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Welcome to Houston!

It is with great pleasure that I personally welcome you to the 2013 AMSAT Annual Meeting and Space Symposium. This is the 31st Space Symposium, reflecting a long tradition (started in the early 1980's) to provide an annual forum for amateur satellite enthusiasts to gather and share their ideas. AMSAT is proud of the technical content of the papers presented over the years reflecting the inventiveness of our volunteers and the significant contribution of presenters to "advancing the radio art."

Once again, the relative importance of the Proceedings in the placement of our technical development work is reflected by the scope of this year's edition. While Congress passed legislation this past January giving the President the authority to make changes to the applicability of ITAR (International Traffic in Arms Regulations) with regard to communications satellites, the regulatory process to modify and implement such changes continues and will not be completed until 2014. Consequently, AMSAT must continue to comply with the existing provisions of ITAR that constrains our ability to share technical information of our satellite development efforts UNLESS that information is first placed in the public domain. The only approach that the Directorate of Defense Trade Controls (DDTC) recognizes for placement of information subject to ITAR in the public domain is by physically publishing the material and then making that publication available to the public at large. Thus, we are once again placing a significant amount of information regarding our Fox-1 program in this year's Proceedings so that we may publicly discuss our project in greater detail and not be in violation of ITAR. It has always been AMSAT's philosophy that we freely share information about our programs to the extent allowed by US law.

We are celebrating at this year's Symposium the 30th anniversary of amateur radio involvement in human space flight and the evolution of amateur radio into a successful program on board the International Space Station. ARISS (Amateur Radio on the ISS) is an international program that supports educational outreach as well as provides an opportunity for informal contacts between astronauts/cosmonauts and amateur radio operators around the world. The recent delivery of "Ham TV" equipment to the Columbus module by the European Space Agency is a reflection of the continued support that amateur radio holds for communicating with students. Astronaut Owen Garriott, W5LFL on STS-9 in November 1983 was the first astronaut to utilize amateur radio to communicate with personnel on the ground, allowing the general public to speak with U.S. astronauts from space, outside the communications channels of NASA's Mission Control. One of the highlights this weekend will be the multi-media panel on Saturday evening moderated by AMSAT VP-Human Space Flight Frank Bauer, KA3HDO with Owen and other key individuals who initiated this amazing program. Having such a celebration take place in Houston makes it more special as it allows us to have non-AMSAT personnel involved with placing amateur radio on the Shuttle and ISS participate in our special program.

After forty-four years, we continue to develop remarkable satellites with educational outreach that now serves as the basis for future launch opportunities. Your support will provide a bright future.

73,

Barry A. Baines, WD4ASW
President

Amateur Radio on Human Spaceflight Missions—30 Years

Frank H. Bauer, KA3HDO
AMSAT V.P. for Human Spaceflight

Abstract

As I prepared for the enormous challenge of describing the entire 30 year history of Human Spaceflight Amateur Radio Operations in one paper, I was reminded of some sage advice I received 20 years ago from one of the founders and visionaries of this very unique and exciting endeavor. In 1993, as I prepared a forum presentation for the upcoming Dayton Amateur Radio Convention, I was lamenting to Roy Neal, K6DUE, about the challenges of stuffing all of our Shuttle Amateur Radio Experiment (SAREX) efforts into a 30 minute presentation. Roy, a former NBC science correspondent and newscaster, retorted “Frank, if I can communicate all the world’s news in 30 seconds, then I am sure you will be able to present SAREX in 30 minutes.” With that unique perspective from a mentor I feel privileged to have known, I will do my best to live up to Roy’s expectations and provide a concise view of the highlights of ham radio development and operations on the Shuttle, Mir and ISS over the past 30 years. Throughout this paper, references will be cited to enable you to further delve into the comprehensive history of ham radio on human spaceflight. Please avail yourself to this more detailed information to learn more than I can convey in a few pages.

Evolution of Amateur Radio on Human Spaceflight

Starting with the U.S. operations on the Space Shuttle and culminating with sustained international ham radio cooperation on the International Space Station (ISS), amateur radio on human spaceflight missions has evolved through 3 developmental and operational phases. As NASA, its international partners, and commercial space have shifted their human spaceflight objectives and priorities, the amateur radio human spaceflight team has worked diligently to stay in lock-step with the plans and visions of the space agencies and commercial human spaceflight. We are now an integral part of the International Space Station program, having continuous presence as crew flight equipment and a payload since Expedition 1. And we continue to work and evolve our systems to be relevant to the space agencies, to the amateur radio community and to the world’s youth.

This paper will walk the reader through all three phases of crew members using amateur radio in space: Phase I, the early experimental phase, Phase II, the frequent flyer operational phase on

the Shuttle and Phase III sustained, long term operations on Mir and the ISS. This paper will also outline the early international opportunities on Shuttle and Mir which were pivotal in forming the current Amateur Radio on the International Space Station (ARISS) international team.

Phase I

The first phase, the pure experimental phase, introduced new amateur radio hardware and techniques to the Space Shuttle program and accomplished several firsts in human spaceflight history. These include the first communications between astronauts and people on the ground outside of the “official” channels (usually reserved for presidents and heads of state). This occurred on STS-9. Other firsts included the first uplink and downlink of pictures on STS- 51F, the first packet computer-to-computer radio link on STS-35 and the first video uplink on STS-37. Highlights of Phase I are described in the following paragraphs.

The Beginning—Owen Garriott, W5LFL

Owen Garriott, W5LFL, pioneered amateur radio communication from space on his historic STS-9 flight on the Space Shuttle Columbia. Launched

on November 28, 1983, Owen was part of a six man crew that performed 24-hour-a-day international science investigations on the STS-9 Spacelab-1 mission. Garriott carried on board an amateur radio station consisting of a battery powered Motorola MX-300 series 2-meter FM handheld radio connected to a signal adapter module that allowed a standard Shuttle headset and a micro-cassette recorder to be used for communication and contact archival purposes. A



**STS-9 Motorola
Radio**

specially built loop antenna was employed that could be temporarily installed in a Shuttle aft flight deck window. This radio station, developed and certified for spaceflight by Lou McFadin, W5DID from NASA Johnson Space Center and a Motorola Amateur Radio Club team, led by Kai Siwiak, KE4PT, enabled Owen to communicate with hams on the ground by FM voice and CW.

The international ham radio community waited with much anticipation and excitement as W5LFL's mission approached. With the mission underway, many hams could hear Owen's voice on 145.55 MHz FM booming into their living rooms. But no one had yet to have a two-way communication with Owen, due to the many thousands that were simultaneously attempting to make that "ultimate DX" QSO with W5LFL. All Owen could hear was static and partial voices due to the FM capture effect and significant number of ham radio RF signals coming his way. On December 1, the third day of his mission, Owen donned his headset and made history by communicating with Lance Collister, WA1JXN, in Frenchtown, Montana. In his own words, this is how W5LFL's part of the contact went that fateful day:



**Owen Garriott, W5LFL with Motorola
MX-300 Series Radio**

"...U.S. west coast and calling CQ. Calling CQ North America. This is W5LFL in Columbia. In another 30 seconds I'll be standing by. Our spacecraft is in a rotation at the moment and we're just now getting the antenna pointed down somewhat more toward the earth. So I should be able to pick up your signals a little bit better in the next few minutes. So W5LFL in Columbia is calling CQ and standing by. Go ahead.

Hello W1JXN, WA1 Juliet X-ray November, this is W5LFL. I picked up your signals fairly weakly. I think our attitude is not really the best as yet, but you're our first contact from orbit. WA1 Juliet X-ray November, how do you read? Over"¹

This contact was groundbreaking for many reasons. First, it represented the first ham radio contact from a human in space to someone on Earth. Second, it allowed the general public to directly listen and communicate with the Shuttle crew. Prior to this, only NASA mission control personnel or heads of State (U.S. Presidents, etc) could talk to astronauts from space. Owen's flight opened human spaceflight to all on Earth. Through W5LFL, the ham community could witness, first-hand, the science and engineering happening during STS-9 by listening in their ham shacks. Third, the mission also showed that a group of volunteers could successfully build a ham radio station for the Shuttle, get it formally approved by NASA, fly it as an official payload on a human spaceflight vehicle, and ensure that it met NASA's stringent safety and RF compatibility



STS-9 QSL Card

requirements. The confluence of this contact, Owen Garriott's enthusiasm in ham radio and the STS-9 mission opened a new door in human spaceflight where crew members can share their experiences in space by directly communicating with anyone on Earth via ham radio.

During Owen's 10 day mission, he talked to over 250 hams around the world, including contacts with Jordan's King Hussein, JY1, US Senator Barry Goldwater, K7UGA/3 and his two sons, including Richard Garriott, at the JSC Radio Club, W5RRR.

Getting permission to fly the first ham radio station on the STS-9 Shuttle mission was extremely challenging and it wasn't the first time that this was attempted.^{2,3} In fact, W5LFL attempted to get a ham radio station flown on his Skylab 3 mission in 1973. AMSAT's Harry Helfrich, W3ZM, developed a proposal called the SKYLARC (Skylab Amateur Radio Communications) project and submitted it to NASA for Owen's flight on Skylab 3. NASA turned down the proposal, citing the fact that there were no hardware penetrations on Skylab to support an external antenna and the short time from proposal submittal to the mission. Despite this setback, Owen's interest in radio propagation and ham radio was infectious, and ten years later, a second attempt was made to fly ham radio, this time on Owen's next flight, STS-9. AMSAT's Bill Tynan, W3XO led the proposal development, with guidance, support and encouragement from NASA

Johnson Space Center Amateur Radio Club members Dick Fenner, W5AVI and Chuck Biggs, KC5RG, NASA JSC Chief of Public Affairs, who was instrumental in getting NASA support within the Johnson Space Center. Roy Neal, K6DUE, carried the torch to NASA Headquarters where he convinced General James Abrahamson, NASA's Associate Administrator for the Space Shuttle Program, that amateur radio on Garriott's flight was worth doing. The proposal was jointly submitted to NASA by AMSAT and the ARRL and was approved in April 1983.

The barriers overcome to enable the STS-9 amateur radio communications to occur set the stage for a rich future of astronauts and cosmonauts conducting amateur radio operations in human spaceflight vehicles. The human spaceflight amateur radio team conducted a steady and ever increasing cadence of human spaceflight ham radio activities, including technological firsts through ham radio experimentation, "frequent flyer" payload status on the Space Shuttle, educational outreach opportunities in schools and museums, satellite deployments by the crew, and permanent, international ham radio presence on future human spaceflight vehicles, including Mir and the International Space Station. A firm foundation and amazing future was finally realized, with nearly 24/7 ham radio operations in multiple locations on ISS.

It is interesting to note that during the AMSAT Symposium which was held during Owen's flight, AMSAT President Tom Clark, W3IWI, in his address to the symposium audience, stated that one of the fundamental motivations of W5LFL's flight was "to encourage technical careers among youth".⁴ What a prognostication that rings true with the SAREX and current ARISS initiative!

Phase I: SAREX—Shuttle Amateur Radio Experiment

Tony England, WOORE

With Owen's success in-hand, a more ambitious activity was planned for the next ham in space opportunity, the STS-51F Spacelab-2 mission with Dr. Tony England, WOORE on-board. The Space Shuttle Challenger mission, STS-51F, represented the first ham radio mission to be called SAREX, the Shuttle Amateur Radio Experiment. SAREX was a Space Shuttle payload sponsored by the Radio Amateur Satellite Corporation (AMSAT), the American Radio Relay League (ARRL) and the National Aeronautics and Space Administration (NASA). The primary goal of SAREX was to spark student's interest in the science, technology, and communications fields by allowing them to talk to Space Shuttle astronauts using amateur radio. In addition, SAREX increased public awareness of NASA's human spaceflight program by permitting radio amateurs worldwide to talk with the Shuttle astronauts.

Three STS-51F crew members were trained to use the radio system: Tony England, WOORE, John-David Bartoe, W4NYZ, and Commander Gordon Fullerton, ex WN7RQR. For SAREX, the human spaceflight ham radio team wanted to realize the vision of inspiring youth to pursue science, technology, engineering and math (STEM) careers through amateur radio communications on the Space Shuttle. As such, ARRL and AMSAT encouraged local ham radio operators to invite youth groups to participate during SAREX passes. For pre-scheduled events, organizations were asked by the ARRL to submit a plan on how they would involve youth in the contact⁵. Students in

the Young Astronaut Program, the Scouts and other programs, like Big Brother, Big Sister, were among the many groups and schools to hear and connect with WOORE on-orbit.

Station hardware employed for this mission included the Motorola radio system and antenna used on W5LFL's flight for voice operations. Also on-board were cameras and monitors supplied by Panasonic and a Robot 1200C Slow Scan Television (SSTV) converter provided by Robot Research. These supported automated SSTV picture uplink and downlink. These automated capabilities allowed ham radio operations to continue despite the heavy crew workload that was anticipated for the STS-51F space science mission. Operations⁶ included:

- Auto mode downlink SSTV, using the automated Robot 1200C capability, which was the predominant mode due to limited crew operations time
- Youth group ops; 2-way voice to prescheduled schools and organizations
- Open voice 2-way; to all hams on the ground
- Auto mode uplink SSTV; enabling hams to uplink pictures to the Shuttle Challenger crew



SSTV Image of Tony England, WOORE

During the early Shuttle flights, when internet and computer tracking were either rare or non-existent, a tabular schedule, with radio opportunities, was developed and communicated to the media (e.g. ham magazines, bulletins) to facilitate communication of opportune times when the Shuttle crew might be available for ham

contacts. These included Shuttle mission elapsed start and stop times and radio mode of operation for QSOs and informal events with schools. During the mission, NASA Amateur Radio Clubs at Goddard (WA3NAN), Johnson (W5RRR) and JPL (W6VIO) provided bulletins, pass times and updates to keep the ham radio community informed. WA3NAN provided simulcast information and shuttle mission audio retransmissions on up to 3 HF frequencies and VHF.

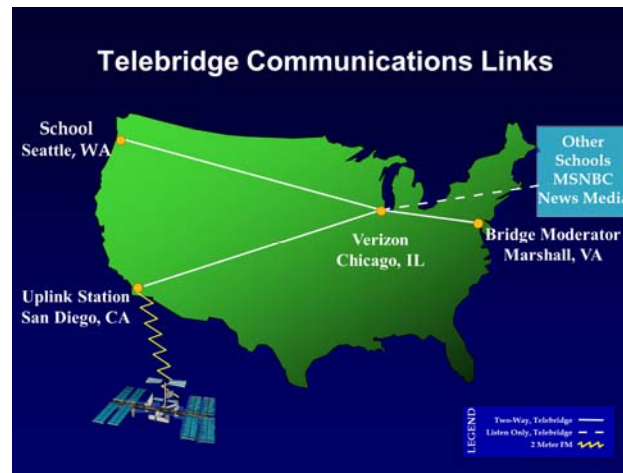
STS-51F was launched on 29 July 1985 and landed on 6 August 1985. By the conclusion of the mission, thousands of hams received and recorded the automated SSTV pictures sent down from Challenger, hundreds of hams around the world talked with Tony, W0ORE, and over 6000 of our nation's youth participated in the ham radio activities on Challenger through voice contacts and picture exchange. As a result, the January 1986 QST stated that SAREX on STS-51F "not only was deemed a tremendous success by NASA and will help obtain similar flights in the future, it also enabled countless young people around the world to enjoy an experience of a lifetime." This mission represented the first time that pictures were uplinked and downlinked to the shuttle.

Ron Parise, WA4SIR

Ron Parise, WA4SIR, extended the reach of ham radio and SAREX through his 9 day "Ultimate DXpedition"⁷ flight on the Space Shuttle Columbia. The prime objective of this mission, dubbed ASTRO-1, was to conduct 24/7 ultraviolet astronomy observations using a cluster of three telescopes that would be pointed to various locations in the sky. The Shuttle would be frequently reorienting during the mission to support different astronomical observations. As a result, the window mounted antenna designed for the aft flight deck used on W5LFL and W0ORE's flight would not be viable as this antenna would be pointed to space, not to the Earth. So AMSAT member, Lou McFadin, W5DID worked with the Motorola Amateur Radio Club in Schaumburg, Illinois, to design and fabricate a dual port annular

slot 2 meter/70 cm antenna that could be mounted on the left and right-most cockpit windows near the Shuttle Pilot and Commander's seats⁸. Either of these windows provided Earth viewing during Ron's flight, depending upon vehicle orientation. This antenna was ultimately used for all future SAREX missions.

Ron's flight, originally designated STS-61E, was planned to fly in March 1986, right after the Shuttle Challenger, STS-51L mission. The loss of the Challenger mission and crew on STS-51L delayed ASTRO-1 until December 1990 on the re-designated STS-35 mission.



The 24/7 operational aspects of the ASTRO-1 mission, the low inclination orbit (28.5°), coupled with Ron Parise's available times for operating posed multiple operations challenges. As a result, several new capabilities and techniques were demonstrated on STS-35 that would prove invaluable for future astronaut ham radio operations from space. These include the use of a telebridge—remote amateur radio ground stations bridged with the schools through a telephone connection to allow the school students to talk directly with WA4SIR—and the development and use of the packet radio robot, enabling hams, worldwide, to automatically connect with the on-orbit radio station while Dr. Parise was conducting science observations. These innovations proved invaluable. The telebridge allowed many students and schools in

high latitude locations in the U.S. to communicate with WA4SIR. Without the telebridge, orbit dynamics and crew scheduling would have resulted in very limited school outreach. With these innovations employed, Parise was able to set up numerous (30+) educational opportunities. The telebridge enabled multiple schools to be connected together during a single 10 minute pass, opening SAREX to a much wider audience. The packet robot concept was devised by a team of AMSAT members from the DC area, led by Tom Clark, W3IWI with additional technical input from Bob Bruninga, WB4APR. Howard Goldstein, N2WX, developed the packet robot software. The packet robot was flown on STS-35 and, given its outstanding success on Parise's mission, all future SAREX shuttle flights.



SAREX & ARISS Telebridge Network

Prior to flight, over 860 educational proposals⁹ were received by the ARRL for a pre-arranged school contact with WA4SIR. Of these, 38 were chosen for 2-way connections, 30 via telebridge and 8 direct. Also, 121 were chosen for listen-only connections.

While the schools and ham radio community were anxiously waiting, the STS-35 launch was plagued with a series of delays that resulted from a pesky hydrogen leak in the Shuttle Columbia's propulsion system. Columbia was rolled out for launch several times with an initial launch planned in May 1990.

After multiple attempts and a 6 month delay, on December 2, 1990, STS-35 lifted off on a picture perfect night launch from launch pad 39 of the Kennedy Space Center, starting the WA4SIR's 9 day mission. The ASTRO-1 mission experienced several failures early on that the operations crew worked around to ensure full science success. Despite these operational issues with the primary payload, SAREX, a secondary payload, was a phenomenal success. Ron made over 50 voice QSOs with hams on the ground and over 600 packet radio connections. Packet radio was on the air for 14 hours each day of the mission. Of the 30 telebridge educational events planned, 26 were successful and of the 8 direct educational contacts planned, 6 were successful. Contact failures were mainly attributed to unfavorable Shuttle attitude and/or vehicle blockage from the ground station line of sight. Window antenna gain pattern, particularly a null near station closest approach, was a contributing factor in contact failure. Dr. Parise suggested that in the future that SAREX should reduce the number of schools planned per pass to just 1-2, as compared to 3-4, to ensure all the schools realize a successful event. Lessons learned from STS-35 and some of the other early SAREX flights were factored in to maximize contact success in future human spaceflight school group contacts.



Ron Parise, WA4SIR with SAREX Station on STS-35

STS-37—The Whole Crew is Licensed!

The next SAREX flight and the last mission as part of Phase I, STS-37, bundled educational outreach with unique experimentation. Led by STS-37 pilot

Ken Cameron, KB5AWP, all 5 crew members on this mission were licensed amateurs¹⁰. See table 2. And all five enjoyed communicating with students, schools and ham radio operators throughout the world. Jay Apt, N5QWL, described his experiences by saying “The QSOs made the crew feel connected to people on Earth. It was great to think of the different cultures and what the people were like while we talked to them.”

STS-37 continued the SAREX progress of firsts for human spaceflight. STS-37 was the first mission to receive television on-board a human spaceflight vehicle. Until STS-37/SAREX, no astronaut had received live video from space. Jim Steffen¹¹, KC6A, was the first to transmit live TV pictures to astronauts in space. Cameron was able to see video from several TV ground uplink stations, mainly black and white video. However, some stations were received in color, most notably color video from the Goddard Amateur Radio Club contact via the US Naval Academy dish antenna. Specifically, the following stations conducted successful TV uplinks as part of this experiment: N9AB, WA3NAN, WA4NZD and KC6A. In describing the video clips received, Cameron said, “it was really neat to see a rerun of our own launch transmitted to us while in space!” One of the video uplinks included a video clip scripted by Jay Leno with greetings to the Shuttle Atlantis crew.

Phase II: SAREX Frequent Flyer, Operational Phase

SAREX Phase II, which started in 1992, represented the operational frequent-flyer phase of amateur radio on human spaceflight missions. During this phase of SAREX, the paperwork, tools and operational techniques were honed to allow SAREX to fly up to 4-5 times a year on the Space Shuttle. The early amateur radio experiments required a significant amount of volunteer overhead. Completing the documentation required to fly SAREX on the Shuttle was, in some cases, a full time job. During the two year Shuttle flight stand-down after the Challenger accident,



Jay Leno SAREX Video for STS-37 TV Uplink

the SAREX team made a concerted effort to significantly improve this situation. Several specific SAREX hardware configurations were developed which allowed the generation of generic SAREX paperwork to meet Shuttle payload integration requirements. John Nickel, WD5EEV, was tapped to streamline the paperwork required for SAREX and to coordinate SAREX activities at the NASA Johnson Space Center. Members of the Johnson Space Center Radio Club initiated a successful amateur radio licensing program which has resulted in a large influx of astronauts obtaining their amateur radio licenses. The Crew Training Plan was formalized and made more efficient; generic lessons and educational material were developed by ARRL that could be used for every flight. In addition, a concerted effort was initiated to license NASA’s astronauts. Almost half of the U.S. astronauts currently have ham radio licenses. To support long-term operations, AMSAT set up a network of volunteer mentors who prepared the schools for their SAREX contacts. These volunteers

also provided real-time information bulletins to hams around the world. And for the Shuttle program, this volunteer team provided SAREX support in mission control, Houston for each SAREX Shuttle mission.



SAREX Patch

Prior to Phase II, significant constant lobbying efforts were required by high profile individuals like Roy Neal, K6DUE, to get NASA backing of the amateur radio experiment. Payload sponsorship from the NASA headquarters office of Education gave SAREX a significant boost as an educational payload, reducing the need for agreements on each flight.

The fruit of all these efforts rewarded the SAREX team with an envious frequent flyer status on the Shuttle with 3-5 missions per year from 1992-1996. See tables 2-4. In Phase II, the SAREX payload progressed from a pure experimental payload to an operational payload whose main goal was education.

SAREX Phase II Highlights & Program Details

The following paragraphs provide SAREX Phase II mission highlights and program details.

SAREX Working Group

The SAREX Working Group consists of a core group of "board of directors" that managed the day-to-day SAREX activities and provided strategic guidance and direction to the program. These individuals were instrumental in transforming human spaceflight amateur radio from a pure experimental activity into an operational payload. The SAREX Working Group included a human spaceflight lead from ARRL, AMSAT and the Johnson Space Center Amateur Radio Club with Roy Neal, K6DUE, as the working group lead. Rosalie White, WA1STO/K1STO, was the ARRL representative. Initially Bill Tynan, W3XO, and starting in 1991, Frank Bauer, KA3HDO was the AMSAT representative. And the Johnson Space Center Amateur Radio Club representative and SAREX principal investigator (PI) was initially Lou McFadin, W5DID. After Lou retired from NASA, Matt Bordelon, KC5BTL, was tapped as SAREX PI and SAREX Working Group member. As SAREX Phase II was primarily an educational outreach activity, the SAREX Working Group received NASA guidance from Pam (Bacon) Mountjoy, from the NASA Headquarters Division of Education.

Phase II Station Configurations¹²

SAREX was flown in one of five distinct configurations. Configuration selection for a Shuttle flight was determined by crew availability for attended operations, the number of ham astronauts on-board, Shuttle power constraints, Shuttle weight and balance considerations, and mid-deck locker availability.

Extremely power limited or weight critical missions flew configuration B: battery operated, 2 meter FM voice using the side window mounted antenna and the 2 meter FM Motorola MX-360 HT. STS-45 flew SAREX in this configuration. Flights with severe weight and balance constraints, mid-deck locker storage problems or crew members with little "free" time for attended operations flew configuration C: 2 meter voice via the Motorola HT and a robot packet radio capability using the Heathkit HK-21 TNC. Packet radio operations was performed interactively using the Shuttle Grid laptop computer or in an unattended robot mode. A 12 V DC power supply in the packet module interfaced with Shuttle power to provide battery-free operation. This configuration was flown during the STS-35 and STS-47 missions as examples. When power, Shuttle weight and balance, and mid-deck locker space are not severely constrained, configuration A, configuration D or configuration E were manifested. Configuration A allowed the Shuttle crew to operate SSTV, Voice and Packet. The TNC and 12V power supply are mounted in a special housing that includes the Robot 1200C SSTV scan converter. A Panasonic VCR/Monitor allowed the crew to view the SSTV video. Configuration D is virtually identical to Configuration A with the addition of 432 MHz FSTV uplink (receive only) capability. The ATV uplink module for this configuration was developed by Andy Bachler, N9AB. Configuration D flew on STS-37. For Configuration E, the Panasonic VCR/Monitor is replaced with a Shuttle provided Video Interface Unit (VIU). In this configuration, video from the FSTV or SSTV is viewed on color monitor in the orbiter. This modification results in a 50%

reduction in SAREX payload weight. Configuration E was flown on STS-50.



STS-50 Commander Dick Richards, KB5SIW, with Addison Elementary School SSTV Uplink

School Group Technical Mentoring

On the early SAREX missions, some of the school groups were ill prepared for the SAREX contact due to lack of technical information or guidance. This led to either missed or very weak contacts. In October 1992, an international operations team was formed by AMSAT-NA to significantly enhance the technical support to the school groups. Beginning with the first SAREX mission in 1993, each school group was assigned a technical mentor familiar with satellite communications. The primary responsibilities of this mentor were to provide guidance in the school technical setup, to be on-hand for any questions or problems, and to be a conduit for vital information before, during and after the contact. Weekly telecons are held with the operations team to ensure they have the latest information and were progressing with their schools. As a result of these efforts, the contact success rate was considerably improved. Since its inception, the success rate with the schools soared from 66-75% in 1992 to 95+% now. For ARISS, the technical mentor team was expanded internationally, due to the diverse, worldwide ARISS schools contact. Technical mentors continue to be key to school contact success. AMSAT would like to thank the mentors for their outstanding support and dedication in making these school contacts such a huge success. The author would particularly like to recognize

Charlie Sufana, AJ9N, who has mentored schools since the technical mentoring project came into being. And for his longtime leadership in keeping the ARISS operations team informed and on top of their school contacts.

Mission Control Support

SAREX was an official shuttle mid-deck payload. As such, the SAREX team provided real-time support in the Mission Control Customer Support Room (CSR) for each of the 25 shuttle missions with SAREX on-board. Duties in the CSR included informing the mission control personnel of any problems with SAREX, scheduled contact successes (and failures), unscheduled contact highlights, and providing real time support to the Mission Control team. In addition, the SAREX team provided a summary of the day's events 2-3 times a day and generated SAREX-related teleprinter messages which were uplinked to the crew. The members of the JSC ARC and other selected SAREX team members from AMSAT-NA volunteered their time to maintain a 24 hour-a-day presence in the Customer Support Room from launch until landing.



SAREX Team Members in the Customer Support Room of NASA's Mission Control

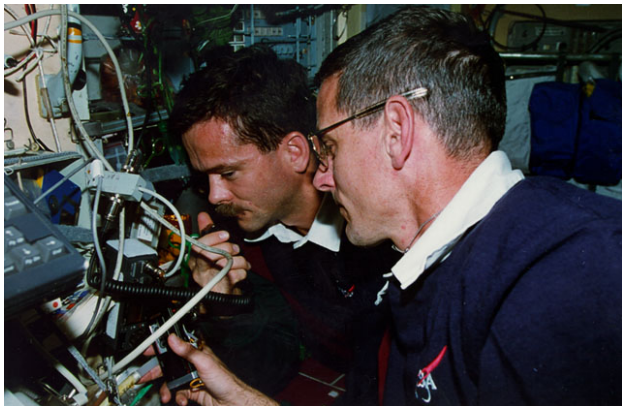
Mission Highlights

STS-45 represented one of the "high water marks" for crew on-orbit operations. The crew was enthusiastic about inspiring youth into STEM careers and saw SAREX as an excellent

opportunity to make that happen. Many of the crew members became rabid operators during the mission. Nearly 1000 voice contacts were conducted during the eight-day mission¹³. Astronaut Kathy Sullivan stated after her flight, "Every time we picked up the radio while flying over the US and Europe, people were waiting and we worked a station every 15 seconds." STS-45 Commander, Charlie Bolden, KE4IQB, has an infectious interest in inspiring students. He picked up the radio and communicated with several schools and family on STS-45 and again on STS-60. (Charlie Bolden is now the current NASA Administrator.)

Coordinating the STS-45 contact at the Belgian Space Camp was Gaston, Bertels, ON4WF. Gaston is the current Chair of ARISS Europe and was the ARISS International Chair for several years.

Other mission highlights of note included STS-50 where over 600 SAREX contacts were conducted and many SSTV images were shared with hams on the ground, STS-59, where 1674 packet radio connections and dozens of voice QSOs were made¹⁴ and STS-74 where Ken Cameron, Bill McArthur and Chris Hadfield made about 100 general contacts per day during their mission.



Bill McArthur, KC5ACR, and Chris Hadfield KC5RNJ, on the Mir Space Station radio during STS-74

Inspiring school students to pursue STEM careers represented the prime objective of the SAREX program. Over the 25 shuttle missions with SAREX on-board, the astronauts conducted over 260 school contacts, enabling thousands of



Current NASA Administrator Charlie Bolden Talking to Students via SAREX on STS-45

students to talk directly with a crew member, allowing tens of thousands of students to hear their school's contact and engaging millions from the general public in this one-in-a lifetime opportunity. The schools were encouraged to pursue pre-contact and post-contact activities to engage and educate the students in space science and engineering. Many took this seriously, developing their own simulated Shuttles and conducting science investigations that emulated their Shuttle/SAREX mission. Others had geography contests that combined amateur radio and Earth observations from space. And still others taught their students fundamental orbit mechanics and had them helping run the SAREX satellite station. While it is not possible to trace the success of our SAREX students we have learned of some notable positive outcomes: one STS-60 female student is now a key science advisor for the Office of Science Technology and

Policy (White House Science Advisor), a young man is an Aerospace Engineer at Northrop Grumman and a young lady graduated with her Aerospace Engineering degree with aspirations of becoming an astronaut.

A Presidential Commendation

SAREX and amateur radio, in general, received a big boost when President Clinton had a telephone conference with the STS-57 crew. During his address to the astronauts, President Clinton commended the astronauts, the SAREX team and the amateur radio community for their outstanding support to students around the world. Clinton said "I understand that later in the mission Janice (Voss) and Brian (Duffy) are going to be talking with school children around the world." He continued "But I want to tell you how much I appreciate the fact that you're making an international education project out of this mission. That's very important to me." Pilot Brian Duffy responded "Mr. President, we find that using amateur radio is an excellent way of communicating with children all around the

world, and we're also able to excite them by using space and science. And letting them see space and science in action, we're able to excite them and hope they'll study harder." The President finished, "You have no idea -- you may be on this mission creating thousands of scientists for the future just by the power of your example and by this direct communication. I think sometimes we underestimate the impact that human contact in an enormously impressive setting like this can have on children all across the world--not only those with whom you'll talk, but millions of others who will just see it and know that it happened"

SAREX Transition

As more and more flights traversed to the Mir space station and ultimately to the ISS, it became more and more challenging to reserve astronaut time and shuttle cargo space and mass for SAREX. As a result, SAREX opportunities on the Shuttle dropped precipitously in 1997 and ended in 1999. However, the SAREX team transitioned with the astronauts, onto Mir and ultimately ISS.



Dick Richards and Ellen Baker Show off their Callsigns, and their "Tang" on STS-50

Phase III—International, Permanently Tended Operations

In Phase III, ham radio on human spaceflight transitioned from short duration, intense, Space Shuttle flights to long duration U.S. presence on the Russian Space Station MIR and finally permanently tended human operations on the International Space Station (ISS). As was required when SAREX transitioned from Phase I to SAREX Phase II, the team, hardware, documentation, and operations all evolved to better serve the new needs—in this case, sustained, long duration activities in space during the Phase III era. Since both MIR and ISS represent international facilities, the Amateur Radio on the International Space Station (ARISS) team was formed in 1996 to support international development and operations on these vehicles. The intent of ARISS is to develop and operate the station systems on ISS as a single coordinated entity. In this way, a single focus and entry point is created for all amateur radio activities on the ISS. The ARISS international team works with and leverages the capabilities and priorities of the international space agencies. They also are working with commercial companies (e.g. Space Adventures) to ensure commercial spaceflight participants gain access to the amateur radio capabilities on the ISS during their on-orbit stay. With the development of ARISS, the foundational development and ops processes honed in SAREX Phase II have evolved into international development and operations capabilities that leverage the strengths and resources of the international team. As a result, a bright, sustained future lies ahead for ham radio in space and more comprehensive, evolving educational activities abound.

International Operations Pre-Mir

Just a few months after Tony England's SAREX flight on STS-51F, two German astronauts and a Dutch astronaut carried a 2-meter, 70 cm amateur radio station on board the STS-61A Spacelab D1 mission. Dr. Ernst Messerschmid, DG2KM, Dr. Reinhard Furrer, DD6CF, and Dr. Wubbo Ockels, PE1LFO operated amateur radio equipment built

by the Robert Bosch company using the callsign DPOSL¹⁵. The radio system was a 2-meter up/70 cm down FM cross band repeater that included an automated uplink recording mode. The Spacelab D1 module included an antenna feedthrough and externally mounted antenna, making communications with the Space Shuttle much easier than with the SAREX window antenna. Spacelab D1 was launched on the final successful flight of the Space Shuttle Challenger on October 30, 1985. The author was one of many stations that successfully worked this mission. The German team flew DPOSL again on the second German Spacelab mission, Spacelab D2 on STS-55. As part of this mission, an antenna test was performed between the SAREX window antenna and the German externally mounted antenna. Students were encouraged to participate and provide their observations as part of the educational aspects of this SAREX flight.

International Operations—Mir

A series of events occurred in 1988 which culminated in amateur radio operations on Mir on November 8, 1988¹⁶ between Leonid Labutin, UA3CR and Musa Manarov, U2MIR. In March 1988, Musa Manarov asked for copies of the Russian Magazine "Radio" to be sent up to Mir. This resulted in an earnest effort by the Radio magazine staff to help the on-orbit crew get their amateur radio licenses and to send up amateur radio equipment. All three cosmonauts on board, obtained their licenses: Commander

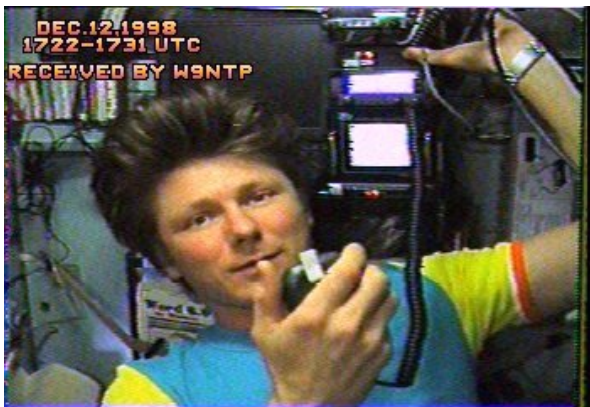


Musa Manarov, U2MIR

Vladimir Titov, U1MIR, Musa Manarov, U2MIR and Valery Polyakov, U3MIR. The first amateur station on-board Mir was

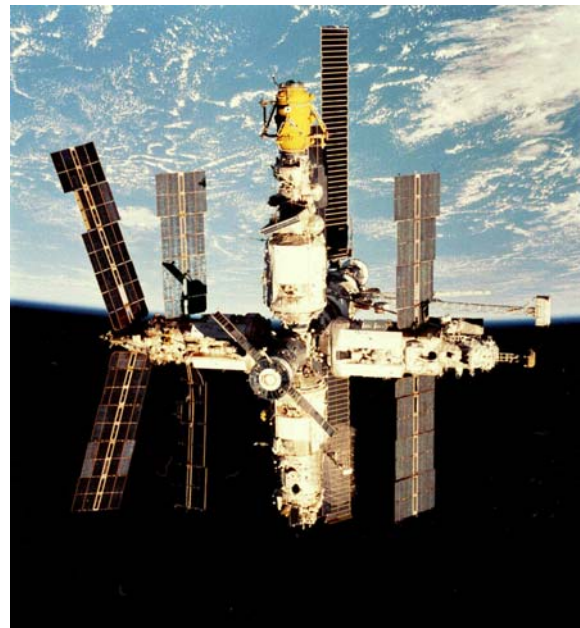
donated by Valery (Larry) Agabekov, UA6HZ. (Note that Larry is currently one of the ARISS Russia delegates). The station, a Yaesu FT290 was delivered to Mir using the Progress-37 cargo vehicle. A commercial antenna was up-massed to Mir on the subsequent cargo flight (Progress-38). During a regularly scheduled EVA on October 20, 1988, U1MIR transferred the antenna to U2MIR who mounted the antenna on a handrail. After the first contact on November 8, Leo made another QSO with U2MIR, this one on November 12 in the US, using Byron Lindley's station as W4BIW/M while at the 1988 AMSAT Space Symposium in Atlanta.

Over the years, several upgrades were made to the Mir radio station by international partners in Russia, Germany, the U.S. and Austria. These include a 10 watt 2 meter transceiver that was carried up with the crew that replaced U1MIR & U2MIR on Mir, an ICOM-228A, PacComm Handi Packet and laptop for packet radio operations in 1991, and a digital voice memory module in 1992 by German astronaut DP1MIR. In 1995, a Kenwood TM-733, dual band (2 M/70 cm) antenna and PacComm 9600 bps packet modem was installed. This radio system, an SSTV capability and the German SAFEX-II 70 cm repeater, mounted in the Priroda module remained the mainstay capability for Mir until the end of mission. Note that all the U.S. crew



SSTV Image Received by Don Miller, W9NTP of Russian Commander Gennady Padalka

members that resided on Mir utilized this equipment for school contacts, family contacts



Mir Space Station

and general QSOs. Also note that the SAFEX-II repeater project leader was Thomas Kieselbach, DL2MDE, one of the charter members of ARISS and an ARISS-Europe delegate until his passing.

U.S. Operations on Mir

Continuous US presence on Mir started with the transfer of Shannon Lucid from STS-76 to Mir on March 22, 1996. Then continuous SAREX amateur radio operations on Mir started when Shannon was replaced by John Blaha, KC5TZQ during the STS-79 flight in September 1996 through to Andy Thomas's expedition which ended in June 1998. Table 1 depicts the continuous string of 5 astronaut hams that resided on the Mir space station for nearly 2 years. U.S. astronauts learned valuable lessons on Mir during their 4-6 month stays. During this time, the US crew members on Mir performed numerous SAREX school group contacts, sent packet radio mailbox messages and talked with ham radio operators on the ground. Ham radio became an important communication resource during the Progress collision on June 24, 1997. Mike Foale sent down many messages using the packet mailbox, as shown in the following figure. Lessons learned on Mir, coupled with the substantial international coordination with Russian colleague Sergey Samburov, RV3DR and team members from the US Mirex team and



Andy Thomas, KD5CHF/VK5MIR at the Mir Ham Radio Station

German SAFEX team, set the stage for international amateur radio coordination on ISS as the ARISS program begins.

Posted : 06/28/97 17:58

To : ALL

From : R0MIR

Subject: Mir Status

We have now got the base block, the module Kvant 2 back on line, leaving 2 more modules. Working very hard, lights in our mouths, in the dark, moving batteries about, to enable better charging, with solar arrays. O2 electrolysis soon, in old Kvant. Much interest from control center to do internal eva to reconnect power to lost Spektr module, to receive its substantial electrical power from its large arrays.

Thanks for all your good wishes. Mike.

CMD(B/H/J/K/KM/L/M/R/S/SR/V/?)>

Astronaut	Expedition	# Schools	Notes
John Blaha, KC5TZQ	Sept 1996-Jan 1997	8	
Jerry Linenger, KC5HBR	Jan-May 1997	9	Mir Fire
Mike Foale, KB5UAC	May-Oct 1997	0	Progress Collision with Spektr Module on June 24, 1997
David Wolf, KC5VPF	Oct 1997-Jan 1998	7	
Andy Thomas, KD5CHF/VK5MIR	Jan-June 1998	8	End of US presence on Mir

**U.S. Licensed Amateur Radio Operators on Mir
Table 1**

ARISS¹⁷

Amateur Radio on the International Space Station (ARISS) represents the first educational outreach program to fly on the International Space Station (ISS). The astronauts and cosmonauts work hard on the International Space Station, but they plan to take some time off for educational activities with schools. The National Aeronautics and Space Administration's (NASA's) Education Division is a major supporter and sponsor of this student outreach activity on the ISS. This meets NASA's educational mission objective: "To inspire the next generation of explorers...as only NASA can." The amateur radio community is helping to enrich the experience of those visiting and living on the station as well as the students on Earth. Through

ARISS sponsored hardware and activities, students on Earth experience, first-hand what it is like to live and work in space. Through ARISS, today's youth are inspired to pursue STEM careers.

In 1996, as the International Space Station neared initial hardware delivery, Pam Mountjoy from NASA HQ Education, asked the SAREX working group to spearhead an effort to bring together an international delegation to discuss the future of ham radio on ISS. The reason: to consolidate the many ham radio voices around the world into one voice—a team that would coordinate the development and operations of ham radio on ISS. Invited were representatives from national amateur radio organizations (e.g. the ARRL in the US), AMSAT, and other ham radio groups that

possessed expertise in ham radio on the U.S. Shuttle and Russian Mir space station. In November 1996, the first ISS ham radio meeting was held at the Johnson Space Center in Houston, Texas. In attendance were members from eight national amateur radio organizations, including Russia, Germany, Italy, Japan, Canada, France, Great Britain, and the USA. This meeting served to initiate the dialog on the development and operations of a permanent amateur radio station on ISS. Those humble beginnings really impressed NASA. Actually, NASA was skeptical that an international amateur radio meeting of this magnitude could be accomplished, especially as quickly as was requested. But the team succeeded and the rest is history--the international working group called ARISS--



**Hotel Sign at Conclusion
of 1996 Meeting**

Amateur Radio on the International Space Station--was formed. Today, hundreds of team members from around the world are supporting the development and

operation of the amateur radio systems on ISS. And most importantly, they are inspiring and educating our youth, enabling them to acquire a firm foundation to pursue technical careers.

The primary goals of the ARISS program are: 1) Educational outreach—Through school contacts, ten or more students at each school ask the orbiting ISS crews questions and hundreds of students and family members participate. The nature of these contacts embodies the primary goal of the ARISS program -- to inspire students' interest in science, engineering, mathematics, technology and amateur radio. 2) Crew psychological factors—Contacts can be scheduled with the astronauts' friends and families. Random contacts with the amateur radio public provide a unique opportunity for casual conversations with non-project related individuals. These boost the crew's morale by reducing the sense of isolation. 3) ISS-based Communications Experimentation—

ISS provides a testbed for development of new communications techniques which can be used to develop new educational projects. 4) International Good Will—Astronaut contacts to schools and the amateur community fosters international good will. Joint hardware development provides a forum to enable international technical partnerships. 5) Emergency Communications Backup— Serves as an emergency communications backup, in case the US or Russian communication links go down.



1996 ARISS Inaugural Meeting Attendees

In the opinion of the author, the two biggest ARISS accomplishments have been: 1) the team's enthusiasm to learn from each other's culture to become a high performing international team and 2) the team's ability to demonstrate to the space agencies and the amateur community that the ARISS team can produce results and meet the stringent safety requirements for ISS. These two accomplishments were a requirement for success on ISS. But it was not easy. It took a lot of discussion, arguments, and compromise to make it work. Over the first couple of tumultuous years, ARISS started to gel as a team. Now they are a high performer.

Some specific ARISS accomplishments include:

- the first human spaceflight frequency plan for 2 meters and 70 cm
- Installation of the Ericsson 2 meter radio system and pico-packet for voice and packet in the FGB. This occurred less than two weeks after the first crew arrived (making ARISS the first payload on ISS)
- The development of 4 multi-functional antenna systems that were mounted by 3 EVAs on the periphery of the Russian service module; these support 2 meters, 70 cm, L band, S Band, HF operations and GPS reception
- The installation of a UHF/VHF Kenwood D-700E & D-710 in the Service Module, near the dinner table and window, marking the second station location on ISS
- The installation of L/S band antennas and 2M/70cm antennas on the Columbus Module
- The installation of the Ericsson 2 meter radio system to support voice and packet in the Columbus Module, marking the third ham station location to date. ARISS now has the ability to operate in 3 different modules—Zarya (FBG), Zvezda (Service Module) and Columbus
- The installation of two different SSTV capabilities, the Kenwood VC-H1, delivered by spaceflight participant Richard Garriott in 2008 and the computer controlled Spacecam SSTV system
- The development of a Ham TV system, led by ARISS Europe, enabling the crew to downlink TV pictures to schools and ham radio operators worldwide
- The successful completion of over 856 international schools to date—kudos to the operations team, education team and volunteer mentors on a job well done!
- 37 ISS expedition crews using our radio system to conduct thousands of QSOs with hams on the ground
- An ARISS contact as a segment of the IMAX Space Station 3D movie



**Bill McArthur, KC5ACR operates
Kenwood D700**

- Over 15,000 students touched each year
- Millions, worldwide have heard an ARISS connection
- Witnessing students, worldwide, become scientists and engineers as a direct result of the ARISS connection
- The first Spacesuit satellite—SuitSat-1/Radioskaf deployed from ISS.
- The first satellite deployed from ISS with a student payload--ARISSat-1

And many, many other accomplishments too numerous to capture in this paper.



Frank Culbertson at the ARISS Station



**Astronaut Peggy Whitson with one of the
ARISS Antennas Prior to Installation**

Spaceflight Participants

The ARISS team has had the unique opportunity of supporting 7 of the 8 spaceflight participants that have flown to the ISS. Our volunteer network has aided them in license training, license testing, equipment training and on-orbit operations support. We have supported their efforts to connect to friends, family, schools and ham radio operators on the ground through the ARISS amateur radio system. The table below depicts the spaceflight participants that have utilized the ARISS ham radio system. Our relationship with the spaceflight participants has been a win-win for the participant and ARISS. ARISS has provided a

Spaceflight Participant	Dates
Dennis Tito	April 28-May 6, 2001
Mark Shuttleworth	April 25-May 5, 2002
Greg Olsen	October 1-11, 2005
Anousheh Ansari	Sept 18-29, 2006
Charles Simonyi	April 7-21, 2007
Richard Garriott	October 12-23, 2008
Charles Simonyi	Mar 26-Apr 8, 2009

vital link to the spaceflight participant's friends and family. And the spaceflight participant has supported numerous ARISS school contacts, they have conducted contacts with thousands of hams radio operators, they were responsible for delivering ARISS hardware systems to the ISS, (e.g. Kenwood VC-H1 SSTV communicator) and have helped ARISS checkout key systems, including the SSTV capabilities.

American Dennis Tito was the first person from the general public to pay for a ride to ISS. When Dennis requested the use of our equipment during his stay on ISS, we worked with NASA, Energia and Mr. Tito's team to ensure that ARISS fulfilled the ISS international agreements and served Mr. Tito. Given that Dennis was the first citizen to fly to ISS, the paperwork and approval process was challenging. And ARISS, being an member of the ISS team, experienced these challenges first-hand. But shortly before he was scheduled to fly, the green light was given to

proceed. Dennis was quite pleased to use the ARISS equipment to talk to his family once per day during his stay on ISS. You could hear the sheer excitement in his voice as he talked to his family about his journey into space.

Mark Shuttleworth and all follow-on spaceflight participants performed pre-scheduled school



**2 Ham Radio Generations in Space
Owen, W5LFL (L) & Richard Garriott, W5KWQ (R)**

contacts and communicated with ham radio operators on the ground.

Richard Garriott's flight to ISS stands out in many ways. Richard was the first second generation American to fly in space. Richard's dad, Owen Garriott, W5LFL, pioneered amateur radio in space on STS-9 in 1983. When first licensed, Richard requested the callsign W5KWQ as it was his grandfather's, making Richard a third generation ham and resulting in all three generations of Garriott's having a space connection. Richard had successful contacts with 7 several Challenger Learning Centers in the U.S., the Austin Liberal Arts and Sciences Academy in Austin, Texas, the Pinehurst School in Ashland, Oregon, the Budbrooke School in the U.K., and the National Space Challenge in Kuala Lumpur, Malaysia. Garriott also conducted random chats with scouts world-wide as part of the amateur radio "Jamboree on the Air".



Budbrooke School Contact

Richard generously flew a Kenwood VC-H1 SSTV communicator on his Soyuz flight and delivered it to ISS for ARISS operations. He also personally set up and checked out the VC-H1 for his use and for future ARISS use. He supported SSTV operations using the Kenwood VC-H1 and the Spacecam & MMSSTV software that are installed on the ISS laptop. At the conclusion of Richard's mission, he made over over 500 random voice QSOs and over 1000 SSTV images sent during his mission. He was well prepared! And, in the footsteps of his father, he made a phenomenal impression on the world-wide ham radio community. Our thanks to Richard and all the spaceflight participants for their outstanding ARISS support.



**SSTV Picture of Richard Garriott,
W5KWQ from the ISS**

The Future

The thirty years since the first ham radio operations by a crew member in space, an

international team of ham radio enthusiasts have accomplished some marvelous achievements for ham radio and school children around the world. We now have a permanent ham radio system in space. At this juncture, it is unclear what human spaceflight's next destination will be. Surely, it will be beyond low Earth Orbit. As the international space agencies work this out and develop a common vision, the ARISS international team is prepared to evolve again to ensure amateur radio is part of the crew's journey. To paraphrase Sergey Samburov's great-grandfather, Konstantin Tsiolkovsky, this ham radio team is looking at moving away from our "cradle"—Earth—to destinations beyond. We hope you will all work with us as a team as we make this happen!!

Personal Thanks

As the current ARISS International Chairman, I feel privileged to serve as the leader of this outstanding team. I look forward to the future, where many more astounding ARISS accomplishments are on the horizon, including Ham TV, the S-band beacon project and more in-depth educational outreach opportunities. I would like to personally thank all who have poured their hearts into this program to inspire school children and inspire our ham radio community through amateur radio.

Dedication

This paper is dedicated to four founding members of ARISS and an astronaut ham that provided unwavering support to ARISS but have since passed away. Specifically, we would like to dedicate this paper to Pam Mountjoy from NASA, Ken Pulfer, VE3PU from the ARISS Canada Team, Thomas Kieselbach, DL2MDE, from the ARISS Europe team and Roy Neal, K6DUE from the ARISS USA team and Astronaut Ron Parise, WA4SIR.

Pam was the vision behind making ARISS a one ham radio team focal point into the space agencies. As an educational outreach executive at

NASA, she was instrumental in getting NASA behind the ARISS and getting initial funding for SAREX and ARISS.

Ken was a leader, mentor and sage that will be sorely missed. ARISS favored greatly from Ken's vast knowledge and understanding of the workings of the international space agencies, especially the Canadian Space Agency where he was an executive. He was instrumental in guiding ARISS to solution on several amateur radio policy initiatives, including callsign & ITU decisions. He also was key in helping ARISS formulate our terms of reference.

Thomas' excitement for hardware development was infectious. His guidance in the early years was pivotal in the development of the antenna design. His idea and excitement for a digitalker on ISS was a primary reason why the student voices were on-board SuitSat-1. He gave us great ideas and pushed the team hard.

Roy was a key moderator and leader within the ARISS team. When things got rough or

contentious, he would always remind us of our primary objective—to make ham radio a permanent fixture on human spaceflight vehicles.

Ron was a dear friend, passionate ham radio operator, creative thinker (especially when it came to ham radio projects), first class astronaut and a leader who recognized the significant impact that ham radio in space could have in inspiring youth to pursue STEM careers. The amateur radio community is deeply indebted to Ron for bringing his tremendous enthusiasm of ham radio into the astronaut office, into space and to hams on Earth.

**My deepest thanks, thoughts and prayers are
with each of you**

Flight	Date	Ham Crew	# Schools	Modes
STS-9 Columbia	Nov-Dec 1983	Owen Garriott, W5LFL	0	Voice
STS-51F Challenger	July-Aug 1985	Tony England, W0ORE John-David Bartoe, W4NYZ	informal	Voice, SSTV
STS-35 Columbia	December 1990	Ron Parise, WA4SIR	38	Voice, Packet
STS-37 Atlantis	April 1991	Ken Cameron, KB5AWP Jay Apt, N5QWL Linda Godwin, N5RAX Steve Nagel, N5RAW Jerry Ross, N5SCW	10	Voice, Packet, SSTV, ATV Uplink
STS-45 Atlantis	March 1992	Dave Leestma, N5WQC Brian Duffy, N5WQW Dirk Frimout, ON1AFD Kathy Sullivan, N5YYV	17	Voice
STS-50 Columbia	June 1992	Dick Richards, KB5SIW Ellen Baker, KB5SIX	15	Voice, Packet SSTV, ATV Uplink
STS-47 Endeavour	September 1992	Jay Apt, N5QWL Mamoru Mohri, 7L2NJY	8	Voice, Packet
STS-56 Discovery	April 1993	Ken Cameron, KB5AWP Ken Cockrell, KB5UAH Mike Foale, KB5UAC Ellen Ochoa, KB5TZZ Steve Oswald, KB5YSR	18	Voice, Packet SSTV, ATV Uplink
STS-55 Columbia	April 1993	Steve Nagel, N5RAW Jerry Ross, N5SCW Charlie Precourt, KB5YSQ Hans Schlegel, DG1KIH Ulrich Walter, DG1KIM	14	Voice, Packet
STS-57 Endeavour	June 1993	Brian Duffy, N5WQW Janice Voss, KC5BTK	8	Voice, Packet
STS-58 Columbia	October 1993	Bill McArthur, KC5ACR Marty Fettman, KC5AXA Rick Searfoss, KC5CKM	16	Voice, Packet

SAREX Missions 1983-1993

Table 2

Flight	Date	Ham Crew	# Schools	Modes
STS-60 Discovery	February 1994	Charlie Bolden, KE4IQB Ron Sega, KC5ETH Sergei Krikalev, U5MIR	5	Voice, Packet
STS-59 Endeavour	April, 1994	Jay Apt, N5QWL Linda Godwin, N5RAX	9	Voice, Packet
STS-65 Columbia	July 1994	Don Thomas, KC5FVF Bob Cabana, KC5HBV	13	Voice, Packet
STS-64 Discovery	September 1994	Dick Richards, KB5SIW Blaine Hammond, KC5HBS Jerry Linenger, KC5HBR	10	Voice, Packet,
STS-67 Endeavour	March 1995	Steve Oswald, KB5YSR Bill Gregory, KC5MGA Wendy Lawrence, KC5KII Tammy Jernigan, KC5MGF Sam Durance, N3TQA Ron Parise, WA4SIR	26	Voice, Packet
STS-71 Atlantis	June-July 1995	Charlie Precourt, KB5YSQ Ellen Baker, KB5SIX	5	Voice
STS-70 Discovery	July 1995	Don Thomas, KC5FVF Nancy Curie, KC5OZX	10	Voice, Packet
STS-74 Atlantis	November 1995	Ken Cameron, KB5AWP Jim Halsell, KC5RNI Bill McArthur, KC5ACR Jerry Ross, N5SCW Chris Hadfield, KC5RNJ, VA3OOG	5	Voice
STS-76 Atlantis	March 1996	Richard Searfoss, KC5CKM, PLT Shannon Lucid, TBD, MS Linda Godwin, N5RAX, MS Ron Sega, KC5ETH, MS	5	Voice
STS-78/LMS Columbia	June-July 1996	Susan Helms, TBD, MS Charles Brady, N4BQW, MS Robert Thirsk, VA3CSA, MS Jean-Jacques Favier, TBD, MS	11	Voice Packet
STS-79 Atlantis	Sept 1996	Jay Apt, N5QWL, MS Jerry Linenger, KC5HBR, MS	3	Voice

SAREX Missions 1994-1996
Table 3

Flight	Date	Ham Crew	# Schools	Modes
STS-83 Columbia	April 1997	James Halsell, KC5RNI Janice Voss, KC5BTK Donald Thomas, KC5FVF	0 ¹	Voice
STS-94 Columbia	July 1997	James Halsell, KC5RNI Janice Voss, KC5BTK Donald Thomas, KC5FVF	18	Voice
STS-93 Columbia	July 1999	Eileen Collins, KD4EDS Cady Coleman KC5ZTH Michel Tognini, KD5EJZ	0 ²	Voice

Notes: 1-Mission cut short, reflown as STS-94; 2-experimental

SAREX Missions 1997-1999

Table 4

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- 16) "CQ Earth, This is Mir Calling", Valery Kondratko, UV3DQE and Joe Kasser, G3ZCZ, The AMSAT Journal, May 1990
- 17) "ARISS—Ten Years as a Team, Six Years in Space", Frank Bauer, KA3HDO; Gaston Bertels, ON4WF; Robin Haighton, VE3FRH; Keigo Komuro, JH1KAB; Ken Pulfer, VE3PU; Sergey Samburov, RV3DR; Rosalie White, K1STO; Dave Larsen, N6CO; Scott Avery, WA6LIE; & Miles Mann, WF1F, AMSAT-NA Symposium, 2006

Amateur Radio on the International Space Station (ARISS)

Interesting Times: Nov 2012–Oct 2013

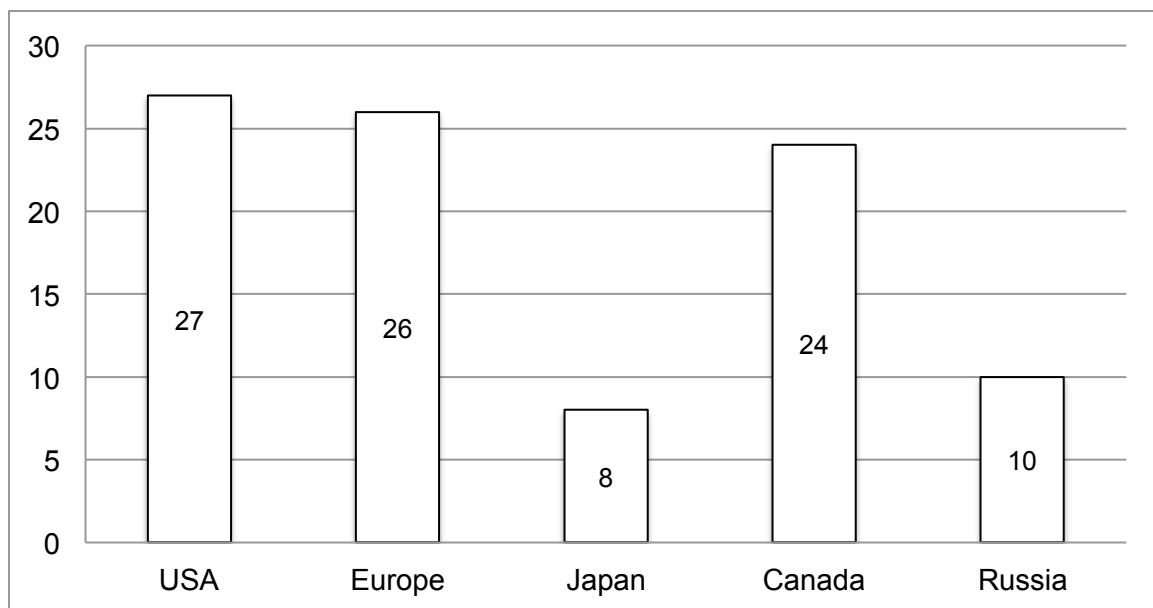
Dave Taylor, W8AAS

w8aas@amsat.org

The past year has been a challenging one, with the sustainability of the ARISS program in doubt. On the hardware side, we've faced abnormal performance from several radios. Programmatically, budget uncertainties and management changes at NASA have kept the team off-balance. Despite everything, ARISS has continued to achieve educational successes, has flown new hardware, and has some interesting new capabilities on the horizon. Work remains to expand our volunteer team, further increase educational impacts, and solidify roles and responsibilities.

Educational Contacts

During the US fiscal year 2013 (Oct 1, 2012 to Sep 30, 2013), we conducted 95 contacts in 21 countries. This is a small increase over last year, when we conducted 89 contacts in 19 countries. The increase was due largely to a record number of contacts for Canada, offsetting a slight drop in US and European contacts. Russia was more active this year, as well.



FY 2013 Contacts by Region

Overall, about 50% of contacts were handled direct, with a ground station at the students' location. This is lower than usual, due to the larger number of telebridges in Canada. (Many of the schools were far north and a direct station could not be set up due to weather or low elevation angles.) In the US, direct contacts continued to make up about 2/3 of the contacts.

The many Canadian contacts stemmed from the presence of CSA astronaut Chris Hadfield, KC5RNJ/VA3OOG, aboard the ISS. He was the first Canadian to command ISS and generated a great deal of public attention for ARISS, both in Canadian news outlets and in social media on the Internet. The Canadian mentor team did a magnificent job of handling their contacts. By partnering with several Canadian companies, they were able to send a team to each school to supplement the educational program. A large poster of Cmdr. Hadfield also traveled to each school. This poster, signed by every student he talked to, was later presented to him.

In addition to formal educational contacts, ARISS conducted two training simulations for the crew. In these, astronauts in Houston talked to real students as part of learning to operate the ham radios on ISS.

Hardware Status

ARISS added additional radio gear to ISS this past year, and changed how some of the equipment is used.

Ericsson VHF

Location: Columbus module

Usage: voice contacts and packet radio

This handheld is a replacement for the original ham radio that was used aboard ISS when ham radio operation began with Expedition 1 in December 2000. The original Ericsson, stowed since 2006, was installed in the Columbus module by ESA astronaut Paolo Nespoli, IZ0JPA, in early 2011. It was used for a few educational contacts, but we experienced problematic contacts, so we returned to using the D700. The Ericsson was eventually returned to Earth for study.

In February 2013, a backup Ericsson radio was flown and installed. Initially, the problems continued. However, during a test pass, NASA astronaut Kevin Ford, KF5GPP, identified and corrected a problem with a loose cable. Shortly after the new Ericsson became operational, the D700 began having problems and the Ericsson became our primary radio for educational contacts.

The Ericsson radio has a lower power output and smaller receive bandwidth (FM Narrow) than the D700. This makes contacts more challenging. Ground stations have achieved reliable performance by using

- Circularly polarized gain antenna
- Antenna polarization switching
- Antenna az/el pointing

- Doppler tracking
- Accurate time synchronization
- FM Narrow mode (3 kHz deviation), when available
- 80–100 W output power
- Low-loss cabling

We have also identified potential obscuration problems with the antenna on the Columbus module. We have been able to limit this issue by avoiding passes that put the ground station on the starboard side of ISS.

Ericsson UHF

Location: Columbus module

Usage: stowed

This handheld is the UHF mate to the Ericsson VHF radio. It was taken from stowage and put on the air on packet radio after the problem with the original VHF radio was discovered. It operated reliably on UHF packet, helping to prove that the new Columbus module antenna was working correctly, until the replacement VHF radio arrived.

Kenwood TM-D700

Location: Zvezda module

Usage: voice contacts (Russia) and packet radio

The D700 had been our primary radio since 2004. Early in 2013, we had some failed and marginal contacts. The Russian team conducted tests to characterize the problem and rule out the antenna system as the cause. The D700 was removed from service in late February and operations were moved to the Ericsson.

The cause of the problem was never determined, but in June the Russians were able to resume using the D700 for packet radio and some voice contacts in Russia. This radio remains problematic and operation is intermittent.

Kenwood TM-D710

Location: Zvezda module

Usage: Russian SSTV experiments

This is not an ARISS radio, but is mentioned here because it is a ham radio. The Russians began using this radio for various SSTV experiments in November 2012, but only over Russia. The radio does not have a microphone and cannot support voice operations.

Ham Video

Location: Columbus module

Usage: stowed

This is an S-band digital amateur television (DATV) transmitter developed by Kayser Italia for ESA. The hardware was flown last August and is scheduled to be checked out soon—possibly late October or early November.

Ham Video is downlink only. For educational contacts, the Ericsson radio will provide two-way voice communications and the combined system will be called Ham TV. This system should enter service for occasional educational video contacts sometime in 2014. You can find a detailed discussion of Ham Video in the Sept/Oct 2013 issue of the *AMSAT Journal*.

Program Challenges

We entered this past year facing a variety of challenges that threatened the sustainability of ARISS. There were weaknesses in our processes, infrastructure, and volunteer team that endangered our ability to accomplish our goals. More seriously, the relationship between ARISS and NASA has been changing in recent years. Taken together, these issues made cancellation of the ARISS program a serious concern.

NASA Support and Budgeting

On the NASA side, most of the problems involved funding and management changes. The changes of greatest concern are these:

- In 2010, ARISS moved from ISS flight crew equipment to become an educational payload under the ISS National Laboratory.

Congress established the National Lab designation to allow ISS to become a utilization funding source. That is, other organizations (both government and private) pay NASA to use ISS facilities. ARISS is not a funding source, so this is a source of tension.

- In 2011, NASA dropped hardware safety support for ARISS projects because of financial concerns related to overruns on ARISSat-1 hardware certification. (As discussed at last year's symposium, the "overruns" were a miscommunication on the NASA side, but it reflected poorly on AMSAT and ARISS.)

This loss of support makes it impossible to build and fly hardware to ISS unless it is paid for by other space agencies or by AMSAT/ARISS.

- In March 2012, all NASA support for ARISS changed from joint funding by the ISS Program Office and NASA Education to Education only. As a result, ARISS is now competing for a piece of a much smaller "pie" (the ISS Program Office budget is about \$3.5 billion; NASA Education's budget is \$0.1 billion).

In addition, Education was reorganized and received a budget cut in October 2012, further stressing the available funding. Because much of the Education budget is ear-marked by Congress, programs like ARISS are hit hard by budget reductions.

Budget issues resulted in several immediate problems during the past year. In November 2012, ARISS lost funding for our Logistics Coordinator, Carol Jackson, KB3LKI. Carol provided significant support to ARISS operations with duties such as updating the web site, scheduling conference and telebridge calls, collecting contact information, and

writing reports. Many of her tasks have been distributed among the volunteer team, but some (such as weekly reports and website updates) remain undone.

NASA contract changes and budget concerns resulted in a temporary loss of support from Kenneth Ransom, N5VHO, for several weeks in February 2013. His position is vital to coordinating operations with NASA, including scheduling contacts with NASA planners and training crewmembers. With help from our supporters in the Education Office, we were able to expedite Kenneth's return and avert a permanent cutback to half-time support, but daily operations suffered for a time. We also permanently lost Kenneth's backup, Steve Ponder, N5WBI. (Tracy Thumm, a scientist in the ISS Program Science Office, is serving as a backup when needed.)

In the longer term, ARISS will be competing with many other activities for dwindling Education Office money. Among other things, this has the following consequences:

- ARISS needs to stay competitive by further improving educational impact
- ARISS will be part of a competitive process for NASA support. This means:
 - A 3-year cycle with yearly project reviews—mediocre activities will lose support
 - Proposals for support will require a detailed educational impact plan and detailed budget
 - Budget overruns could result in cancellation

On the bright side, NASA has kept ARISS alive while many other education programs have been cancelled. For example, during the government sequestration earlier this year, the NASA Associate Administrator for Education identified ARISS as one of several activities that were exempted from immediate suspension. ARISS has a good reputation within NASA and is considered a valuable part of K–16 STEM education.

ARISS Internal Issues

Within ARISS, we have identified a number of risk areas and improvements that need to be addressed. We have been operating well for years, but some tools are outdated and people are stretched too thin. For example, the loss of support from Carol this year forced us to redistribute many tasks, in some cases overloading our team. This, coupled with the hardware issues described earlier, resulted in an unusual number of marginal and failed educational contacts for a short time in early 2013.

Here are some of the areas that need to be more robust, along with the initial steps we've taken to deal with them:

- Operations team and mentors are overworked

We are restricting educational contacts to about 100 per year and working to level the load. We're looking for additional volunteers to join the team and formalizing training to bring people up-to-speed faster and more uniformly.

- ARISS communications and information-sharing media need significant modifications and updates. This includes the public and operations team web sites, mailing lists, and shared materials (presentation slides, tutorials, and so on).

ARRL is leading a redesign of the public ARISS web site. Mailing list membership has been reviewed and volunteers are being sought to review and reorganize the ops web site.

- There are several jobs on the ops team that are potential single-point failures.

We are working redundancy into all of ARISS, especially operations. This includes identifying and training a backup for Charlie Sufana, AJ9N, who maintains the ops database and web site. We've begun updating the software used to predict possible passes for contacts and will train a backup to Gil Carman, WA5NOM, our current orbit master.

Proposals

Waiting for approval by OMB to reopen proposal system

Miscellaneous Notes

ARISS has done a few other things this past year that should be mentioned:

- As part of the Ham Video effort, AMSAT-Italia submitted frequency coordination paperwork to the ITU for the amateur radio frequencies used on ISS.
- An ARISS working group updated the hardware recommendation for ground stations conducting educational contacts.



A Brief Overview of the ARISS Program

David Jordan, AA4KN
ARISS Mentor/PR

Abstract

The flight of Space Shuttle mission STS-9 in 1983 opened the door for ham radio communication with manned spacecraft. During this mission, astronaut Owen Garriot and a dedicated ground support team conducted the first amateur radio contacts with an astronaut circling earth. This was later followed by STS-51F mission where in 1985, the first ham radio contacts between school students and astronauts were achieved through the Shuttle Amateur Radio Experiment or SAREX. Similar experiments were performed on board space station Mir and then with the International Space Station (ISS), where school contacts are regularly scheduled. In this paper, I plan to cover some operational aspects of the ARISS program and the basics for pursuing a school contact with the International Space Station.

The Organization

This whole idea of ham radio contacts with manned spacecraft was initially launched by a small group of ham operators that worked for NASA and over 30 years, has evolved into the Amateur Radio on the ISS or ARISS organization.

ARISS is now international in scope consisting of delegations from 9 countries. Volunteers from these countries coordinate with their individual space agencies such as NASA, ESA, CSA, the Russian Space Agency, etc. International delegate meetings are held occasionally, but the main stream of correspondence is carried out via frequent teleconferences and email.

Currently, Frank Bauer, KA3HDO serves as AMSAT-NA's VP for Human Spaceflight, and Chairman of ARISS-International. Dave Taylor, W8AAS serves as a U.S. Delegate (appointed by AMSAT) along with Rosalie White, K1STO (appointed by ARRL). AMSAT-NA also appoints one of the two Canadian Delegates, Maurice-André Vigneault, VE3VIG.

Operations within ARISS

ARISS operations fall into two categories:

- Operations carried out by the associated space agency of the particular country

Space agency operations consist of tasks such as (1) serving as the official point of contact (POC) for the school or other institution. (2) providing the official Contact Proposal form and/or Application to the school (the Proposal form

will be discussed in more detail later in the text) (3) providing any necessary mentoring to the school as it pertains to their proposed educational curriculum goals in preparation for their contact. (4) Generating lists of possible contact dates/times for the schools to consider (5) determining the final contact date/time from those chosen by the school based on the current ISS work schedule.

□ Operations carried out by volunteers

These tasks can consist of (1) posting press releases covering upcoming ARISS contacts to email lists and related social media (2) archiving audio and video recordings of the contacts (3) posting upcoming ARISS contact schedules to amateur radio email lists (4) serve as official ARISS telebridge stations for relaying ARISS contacts between the contact school and the ISS (4) serve as ARISS contact Mentors for the schools (5) encourage local schools to submit a proposal for holding an ARISS contact for their students.

ARISS Contacts - Direct and Telebridge

To begin, there are two ways that an ARISS contact can be done. One way is the *direct* contact. This is where an amateur radio station is set up at the actual site where the contact will take place such as a school, Museum or other institution. For simplicity in this paper, we'll continue to refer to the contact site as a school. Having a station on site is usually the preferred way since the students, as a bonus, are also exposed to ham radio operation. The other way is by having a station at another location serve as a relay or rather, *telebridge (TB)* station for the contact. The contact is scheduled for a time when the ISS will be passing over the TB station that also accommodates the school's working schedule. The school is linked to the TB station through a landline phone connection. As the ISS breaks over the horizon, the TB station confirms contact with them and tells the students to begin with their questions. This link up continues until the ISS completes its pass.

More about ARISS mentors

Probably the most interesting and fulfilling ways to volunteer in ham radio is to serve as an ARISS mentor, supporting the school hosting the ARISS contact.

ARISS mentors are hams that usually have, in some fashion, been affiliated with ARISS school contacts in the past. Most have operated amateur satellites at some point as ham operators and have developed a good knowledge base on what station equipment is favorable to use, how an amateur satellite station should be configured, and most importantly, be able to help solve station set up problems over the phone or email. As a mentor, you will make new relationships with both school support staff and fellow hams with similar interests and varying levels of experience. Guiding a school and their technical support team (in many cases, the local ham club), to a successful contact with the ISS is challenging and rewarding.

Scheduling an ARISS Contact

Scheduling a contact with the International Space Station might begin with a parent seeing a video clip on the news about a school contact and deciding to approach their child's science teacher with the same idea or a local ham club may decide to take the project on as a club activity and then seek out a local school that would be interested in hosting the event for their students. Before visiting the school, the parent or club needs to gather and review materials about the ARISS program. The best way is to inquire at the American Radio Relay League (ARRL) web site. They are a good source for how to proceed. Go to www.arrl.org and in their Search field, type ARISS. The next step is to request a meeting with the school principal to share ARISS materials, explain an ARISS contact, how the school will be involved and most importantly, to ensure the principal is excited about the event and willing to fully support it.

Once the school has decided to move forward, they will need to submit a proposal form from the NASA Teaching from Space office. For more information on this, visit and review material at <http://www.arrl.org/ariss-proposal->

[requirements](#). There are links there to review the proposal requirements and obtain the form. Once the school completes the proposal, they submit it to the NASA Teaching from Space office for approval. The time between a proposal being approved until the actual contact event is usually around 6 months.

Direct or Telebridge

Next, a decision needs to be made to pursue a direct or telebridge contact. A telebridge contact can be done anywhere as long as the school has a land-line phone available and most do. The direct contact will require a technical support group of local amateur operators with satellite station equipment that can be brought on site and someone in the group that is knowledgeable and experienced in using it. It's rarely the case that your ARISS assigned mentor is local. Concerning technical matters, the mentor should be able to help, but can only do just so much from a distance. These are important matters to consider before choosing the type of contact to pursue. If the direct method is chosen, but you begin to have problems following through, you can change to telebridge, but it most always results in a schedule change and postponing the event.

The Kick Off!

Let's assume the school is approved to host a contact with the ISS. At this point, they have been assigned a mentor by ARISS and NASA Teaching from Space (TFS) gets involved. The TFS coordinator will schedule an online Orientation meeting with the school and mentor where a basic timeline of events leading up to the contact is discussed along with any particular questions the school may have about integrating space studies into their curriculum which is NASA's main focus in promoting ARISS contacts in schools. Toward the end of the meeting, the mentor has a short Q & A with the school.

Preparation for the Contact

At this point, preparation for the contact begins. First, the mentor shares several documents with the school and their tech. support team. Some are forms to collect information from the support groups such as contact numbers from contact support personnel at the school, a Contact Technical form listing the radio equipment that the tech. support team plans to use if the contact is direct, a School Contact Timeline listing tasks to do when to do them, etc. For the next 6 months, the mentor, school and tech. support team are usually corresponding on a frequent basis to ensure all is going well and to resolve any problems that may develop along the way. Also, the school should be busy informing parents, local media and the community in general about the upcoming contact date.

Approaching the Contact Date

Within the last month before the contact, the school begins rehearsals together with the students chosen to talk with the astronaut along with the tech. support team in a simulated contact scenario; ensuring that the students know where to be at each stage of the event, checking and re-checking on-site station operation and in the case of a TB contact, checking phone primary and backup conference phone lines, etc. At the 24 hour point prior to the contact, the school is mandated to submit a form to ARISS through their mentor, declaring they are prepared and ready for the contact.

The School Contact

Excitement begins to build as a group of students make their way to the designated contact area. For a direct contact, the tech. support team has been at the school since early morning, reviewing the station configuration and checking its operation through a local repeater or perhaps monitoring packet transmissions during a timely overhead pass of the ISS. It's now 20 minutes before the scheduled contact and an audience of parents, students and media has gathered in the bleachers of the middle school gym where a temporary stage has been assembled for the occasion. After giving

last minute instructions to the audience, the speaker takes her seat as the tech. support team begins calling the ISS. After four calls, the astronaut's voice slowly emerges out of the noise from the speaker. After a short "welcome on board the International Space Station" is heard, the first student is invited to ask his question. The session is progressing well, until student no. 5 finishes her question, followed only by noise from the radio. The school station continues to call, but no answer from the astronaut. After several more calls, the station operator transmits the message, "changing to backup frequency". After a few seconds pass, a sigh of relief is heard moving through the crowd as "NA1SS on backup frequency... Do you copy?" breaks through the noise and the questions begin again. The session again continues without fault until, after question 15, noise begins to slowly overtake the ISS signal as it begins its descent over the horizon. The station microphone is opened one last time and the contact ends with a big "Thank You" from all those present. The speaker again, mounts the podium and congratulates the school on their very successful contact with the International Space Station.

Summary

Anyone who has ever attended an ARISS contact knows the thrill and excitement it generates and how it is one of those experiences you'll never forget. The goal of ARISS is to provide students with a new and unique way to view science, technology, engineering and math through the all encompassing hobby of amateur radio. As an ARISS mentor, I've had the unique opportunity to witness the inspiration and creativity involved in the preparation for these events. I want to encourage the amateur radio community and especially those who have experienced the excitement of working amateur satellites, to consider helping a school, museum, college or other youth education group in your community, to submit a proposal to hold an ARISS contact.

Resources:

For general information about ARISS: www.ariss.org

For general information about ARISS: www.arrl.org and search "ARISS"

For specific information on ARISS Contact Proposals: <http://www.arrl.org/ariss-proposal-requirements>

**ARISS Contact
Burns Sci-Tech Charter School, Florida**



Burns Sci-Tech Charter School ARISS contact
Oak Hill, FL

photo
D.Jordan, AA4KN



Students created Space Suits
for Contact Day

photo:
D. Jordan, AA4KN

**ARISS Contact at
De Vinci Academy
Florida**



photo:

D. Jordan, AA4KN

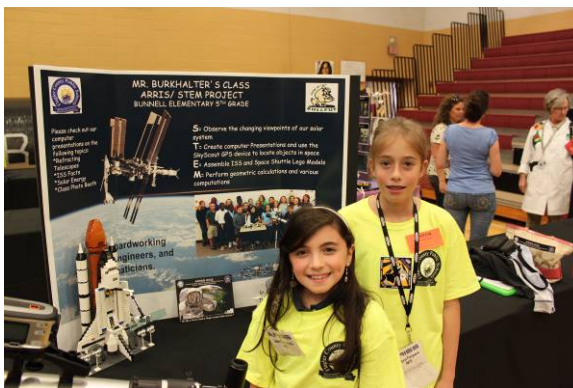
Flagler Palm Coast District-Wide ARRIS Contact Event Florida



Station set up in the School Gym
photo: D. Jordan, AA4KN



Media in on hand for the Contact
photo: D. Jordan, AA4KN



Many of the Participating Schools presented
Student Projects for the Contact Event

photos:
D. Jordan, AA4KN

AMSAT Space Symposium 2013

Fox Satellite Program Overview



Tony Monteiro, AA2TX

Launch Cost Issue



- P3E to GTO..... \$10M
- ARISSat..... \$1M
- MicroSat to LEO..... \$500K
- 3U CubeSat to LEO.. \$300K
- 1U CubeSat to LEO.. \$100K



Launch Strategy



- Take advantage of large and growing interest in CubeSats
- Develop family of CubeSats with ham radio transponders that are attractive for hosting science experiments
- Partner with universities to develop joint science and education missions
- Get a free launch via the NASA ELaNa program

3

Program Phases



- Phase 1 (*Fox-1 type satellites*)
 - 1U CubeSat
 - FM voice repeater
 - FSK Digital data up to 9600 bps
- Phase 2 (*Fox-2 type Satellites*)
 - 3U structure
 - Software defined radio transponder
 - Linear, FM and high-performance digital modes

4

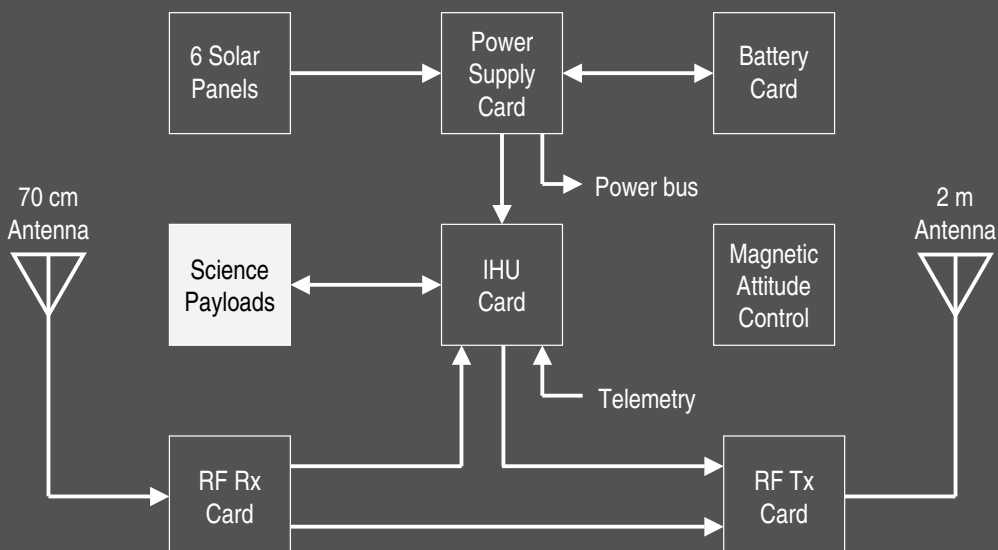
Status



- Nov 2011 - Proposal submitted to NASA for *Fox-1*
- Feb 2012 - Accepted into NASA ELaNa program
- **Scheduled for launch November 2014**
 - ELaNa XII on NROL-55
 - Atlas V launch vehicle
 - Vandenberg AFB launch site
- Orbit is 470 km x 780 km @ 64 degrees
- Orbit lifetime is about 11 years

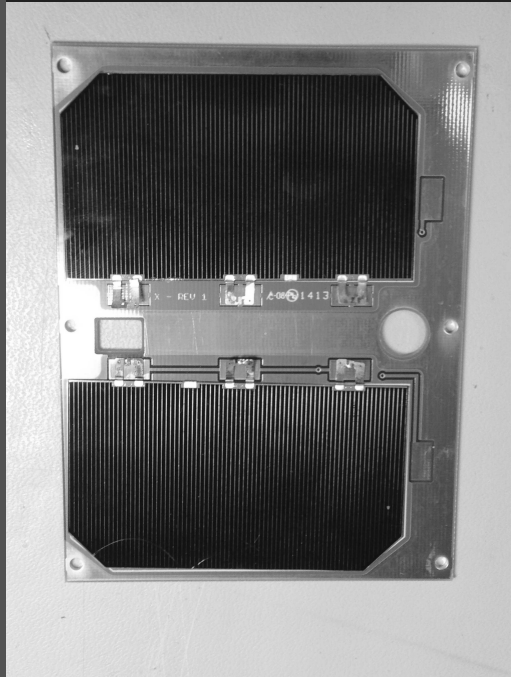
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Fox-1 Technical Overview



6

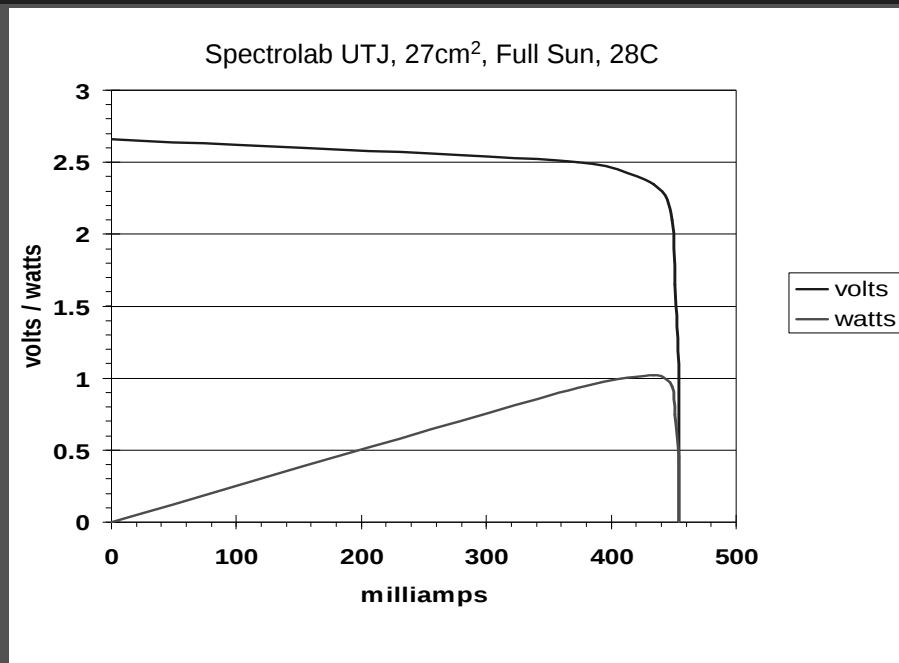
Solar Panels



- 6 solar panels
- 2 cells per panel
- Spectrolab Ultra Triple Junction cells
- Rad-hard
- Space-rated
- 28% conversion efficiency

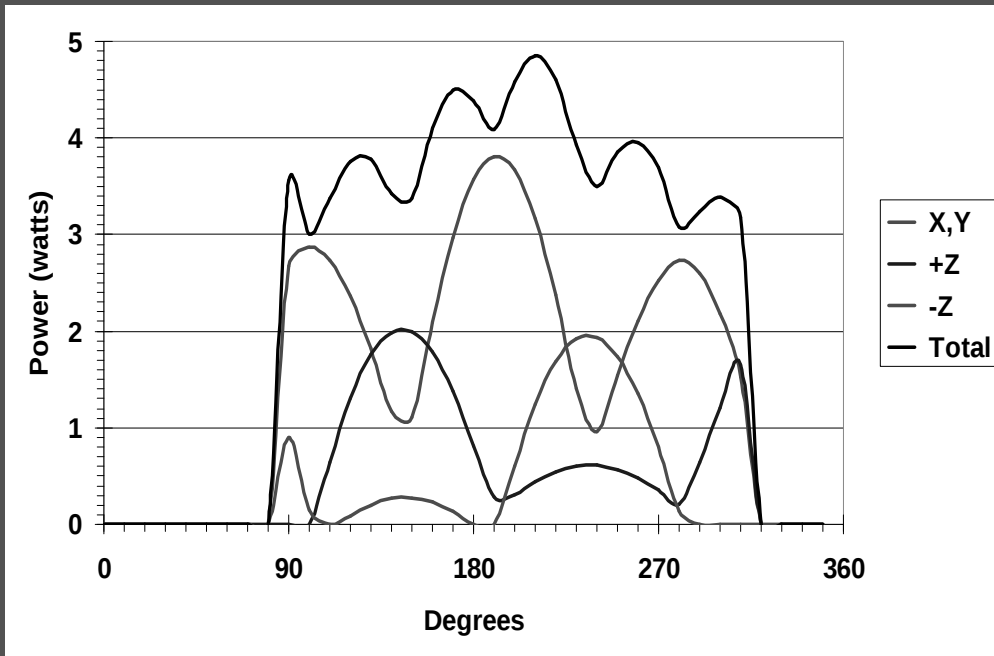
7

Solar Cell Characteristics

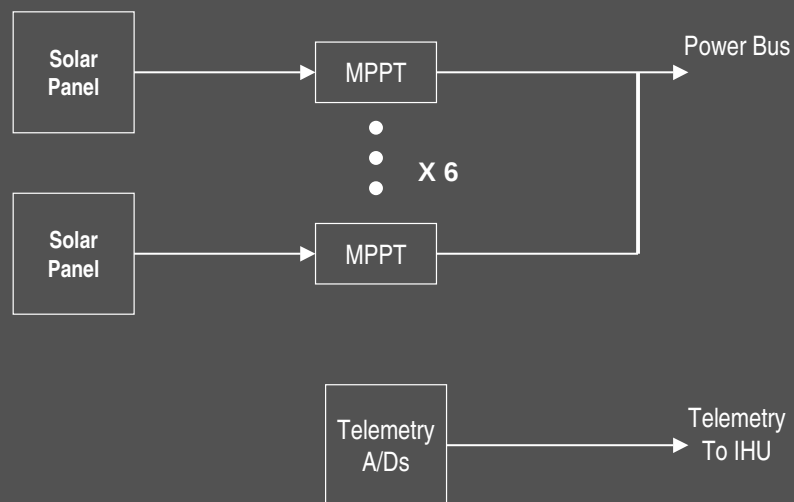


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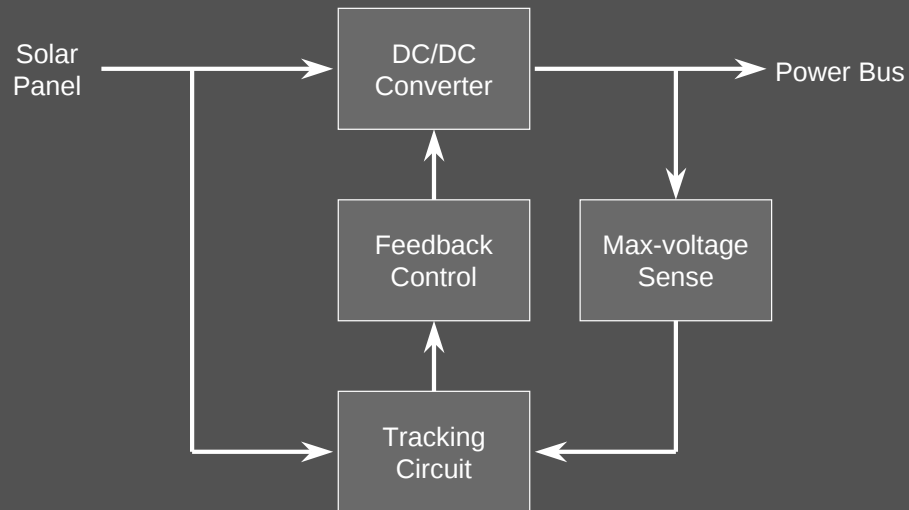
Generated Solar Power



Power Supply Card

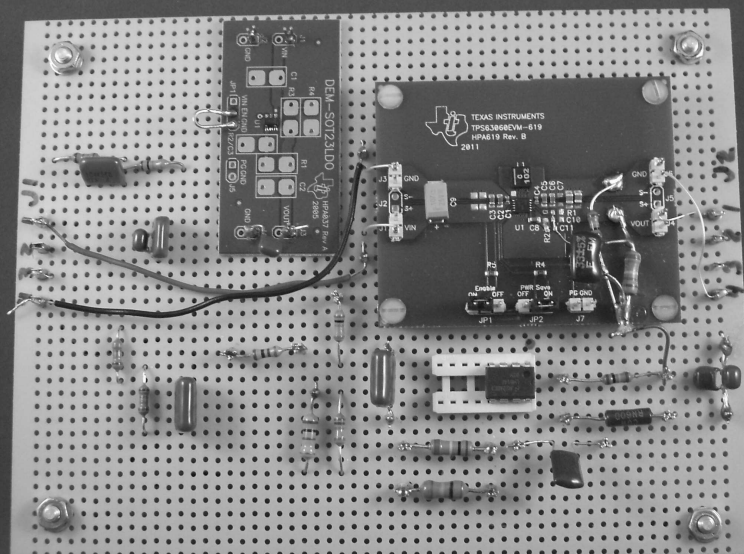


MPPT Operation



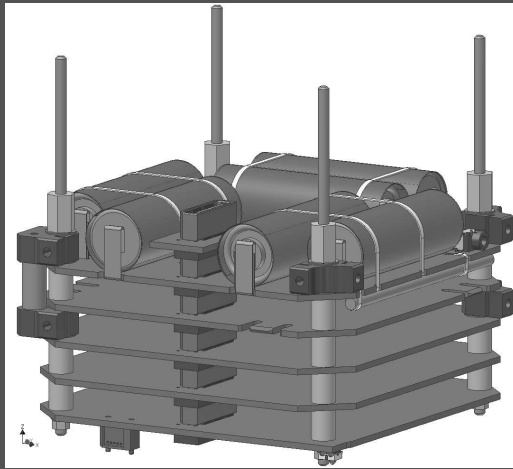
11

MPPT Prototype



12

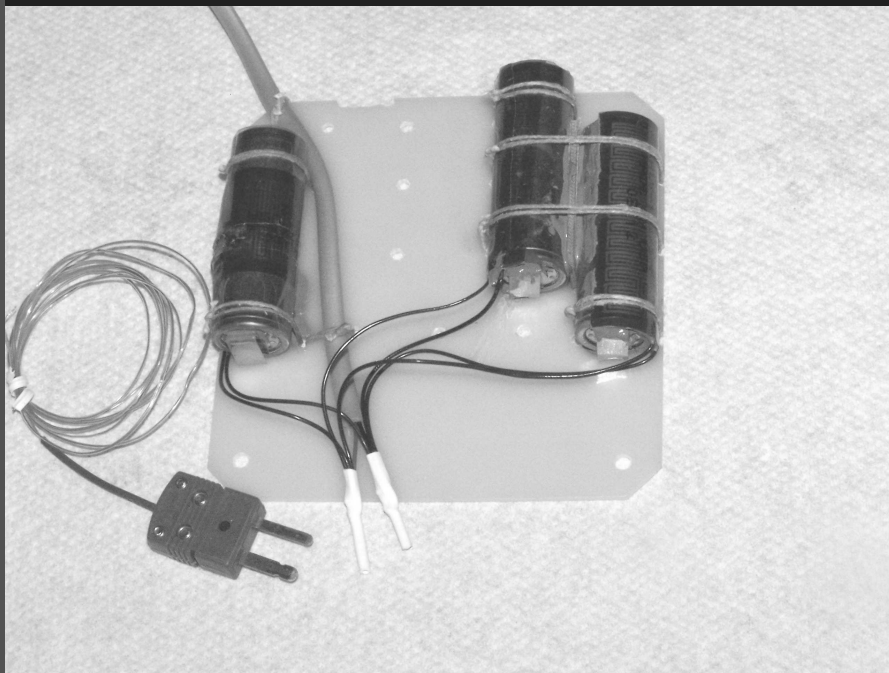
Battery Card



- 6 NiCad A cells
- 3.6 V nominal
- 12 watt-hours capacity
- Active thermal control

13

Battery Heater Test Prototype



14

Internal Housekeeping Unit



- Collects telemetry information
- Operates science experiment
- Generates telemetry downlink as sub-audible FSK mixed with voice signal in transponder mode
- Generates high speed FSK in data mode
- Executes commands from ground control

15

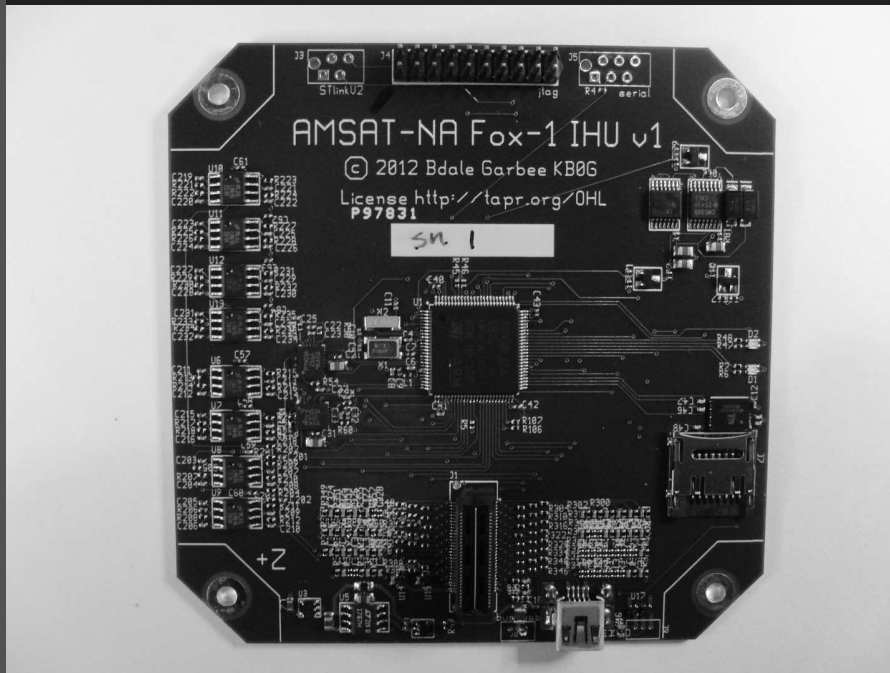
IHU Card Processor



- *Ultra Low Power* ST Microelectronics STM32L
- 32-bit processor / 33 MIPS
- 384K FLASH / 48K RAM / 12K EEPROM
- 128K Magnetorestrictive RAM

16

IHU Card Prototype



17

IHU Software



- Open source SW tools (GNU C compiler)
- LINUX & Windows development environments
- FreeRTOS operating system
- STM32L "Discovery" card for SW development
- Operating system running on IHU prototype

18

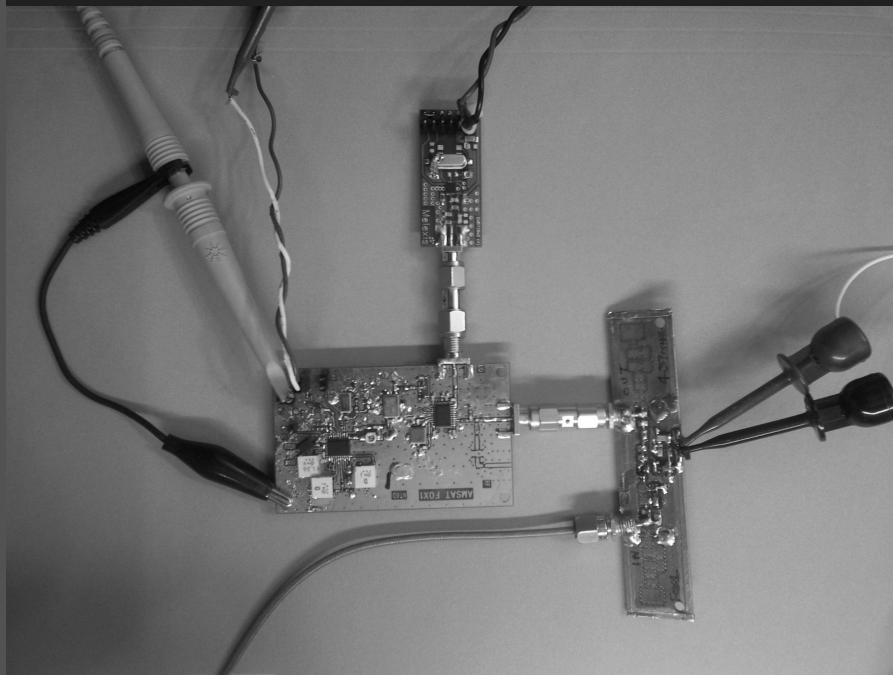
RF Receiver Card



- Operates on 70cm
- FM receiver
- LNA with SAW filter for high sensitivity and interference rejection
- Automatic frequency control

19

Receiver Test Prototype



20

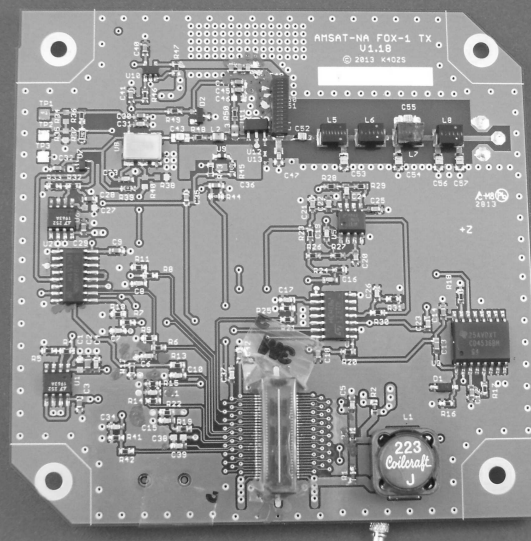
RF Transmitter Card



- Operates on 2 meters
- FM exciter
- Power amp produces 400 mW minimum
- 800 mW max on fully charged battery

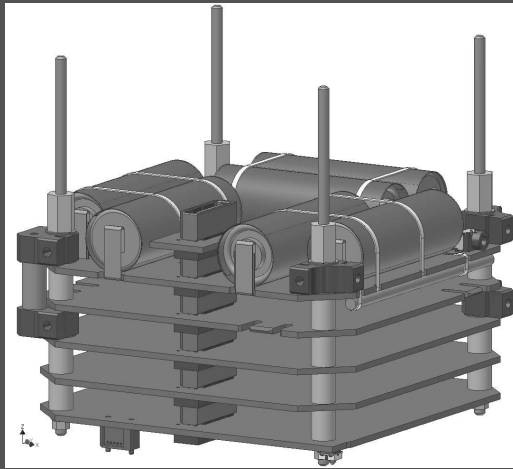
21

RF Transmitter Card Prototype



22

Attitude Control System



- Passive magnetic system
- Aligns satellite z-axis with earth's magnetic field
- Bar magnet on structure
- Hysteresis rods on battery card for motion damping

23

Antennas



70 cm whip →



← 2 meter whip

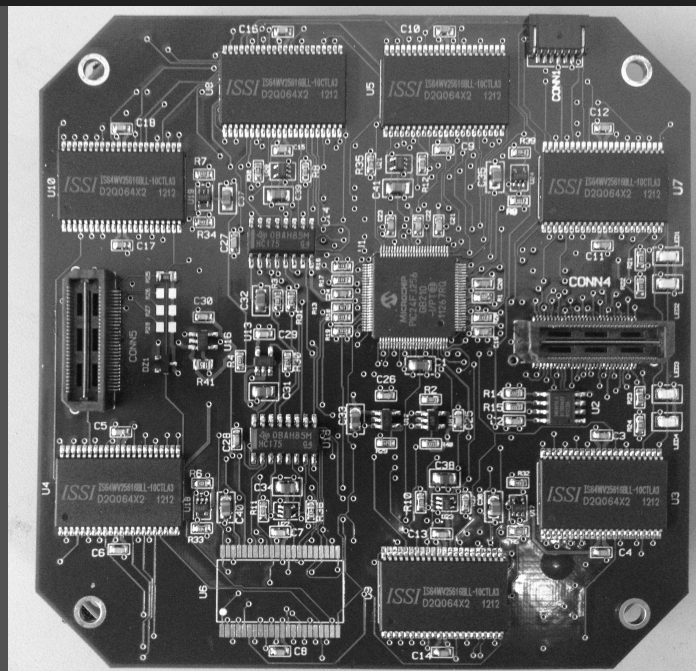
Experiments on *Fox-1*



- MEMs gyros on IHU from Penn State
- Low Energy Proton (LEP) experiment from Vanderbilt University
- JPEG Camera from Virginia Tech

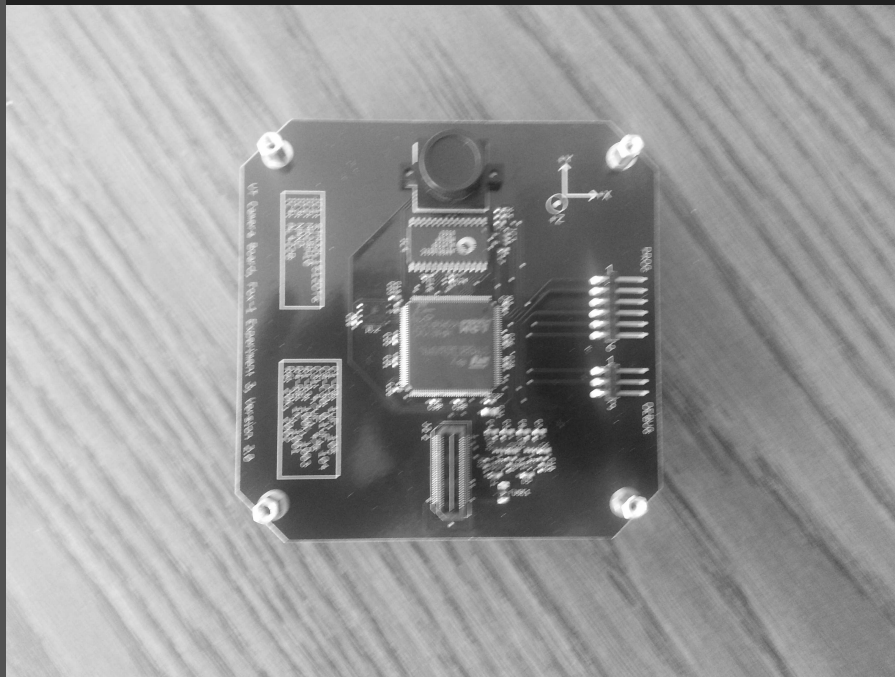
25

LEP Experiment



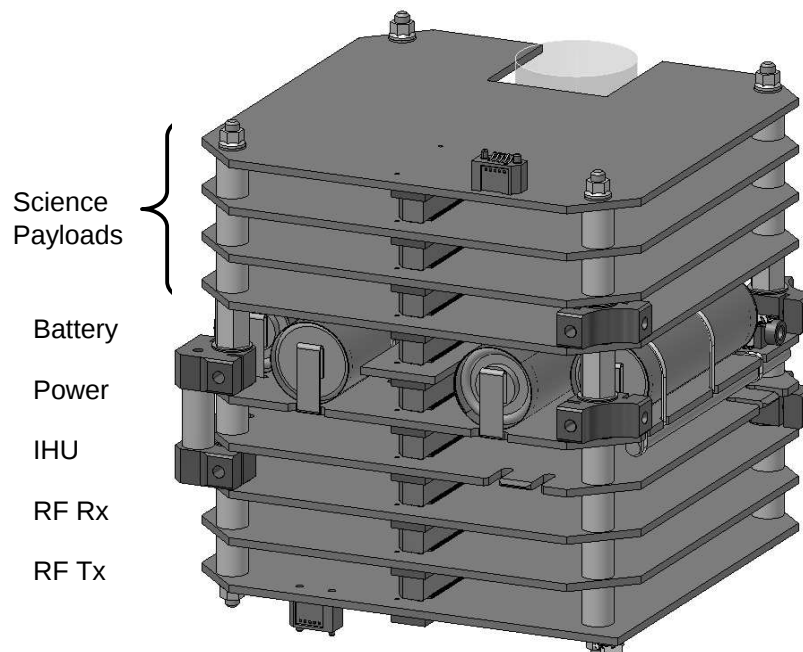
26

Camera Card

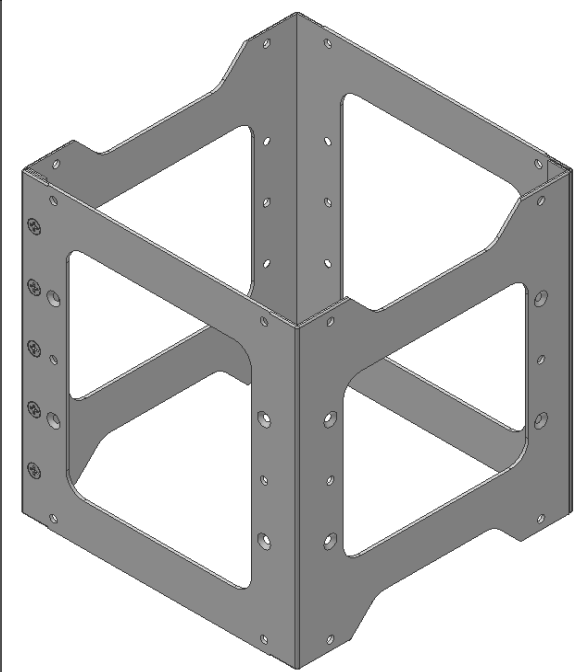


27

Avionics PCB Stack

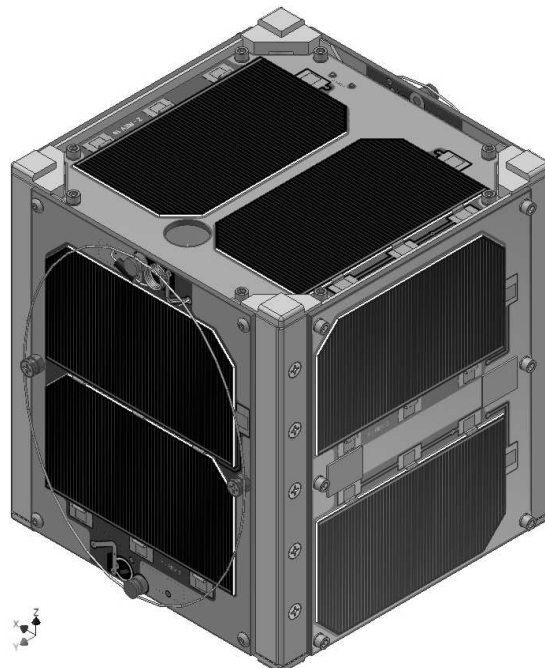


Fox-1 Structure



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Assembled Fox-1 Satellite



Fox-1 Operational Modes



- Transponder Mode
 - FM analog repeater
 - Telemetry/experiment data sent as sub-audible, low-speed FSK simultaneously with voice
- Camera Mode
 - High-speed FSK downlink
 - Color JPEG photos (VGA resolution)
 - 1 photo per minute
 - Telemetry and experiment data multiplexed with image data

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RadFxSat



- *Fox-1* satellite bus
- Space radiation-effects experiments provided by Vanderbilt University
- Experiments run simultaneously with amateur radio transponder
- Proposal accepted into NASA ELaNa program March 2013
- No launch date yet

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AMSAT Classifieds



*** HELP WANTED ***

AMSAT is always hiring!

- **Design engineering:** mechanical, electrical, PCB design systems, software, project management, thermal design
- **Satellite construction:** PCB construction, parts procurement, component fabrication, assembly
- **Satellite testing:** environmental testing, functional testing, requirements and regulatory compliance testing

Contact Tony Monteiro aa2tx@amsat.org

Questions?



FOX-1 Telemetry Coding And Modulation Design

Phil Karn, KA9Q

Paul Williamson, KB5MU

Michelle Thompson, W5NYV

Introduction

The AMSAT FOX-1 satellite is scheduled for launch in November 2014. FOX-1 will carry a conventional FM repeater with an unconventional telemetry design. There will be two modes:

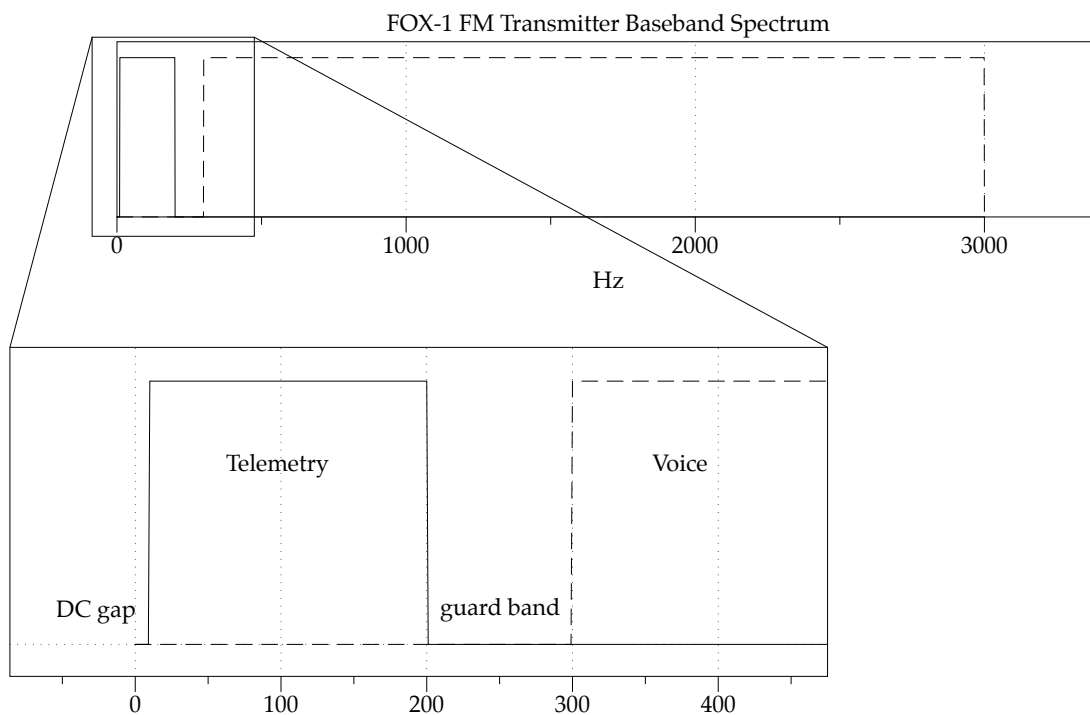
1. A “Full-Speed Data” mode that will run at about 10 kb/s when the repeater isn’t operational. This mode is intended for receiving camera images from the spacecraft.
2. A “Data Under Voice” mode that will run continuously during repeater operation in the sub-audible range below 200 Hz.

Because FOX-1 carries only a FM transmitter, all data will be sent as noncoherent FSK.

Data Under Voice Mode

During normal FM repeater operations, FOX-1 will transmit a continuous telemetry stream at a data rate of 140 bps. This very low rate is necessary because the signal must fit below the normal speech audio band that begins at about 300 Hz. To provide for a margin, the channel signaling rate will be 200 bps, which results in a spectral null at 200 Hz. A relatively simple lowpass filter removes the spectral components above this frequency.

The 60 bps difference between the data and channel bit rates is taken up by forward error correction coding (a Reed-Solomon block code) and line coding for spectral shaping.



Forward Error Correction

AMSAT's extensive experience with LEO satellites suggests that the primary impairment of the FOX-1 telemetry channel will be slow fading due to a non-uniform antenna pattern, slow spacecraft rotation and a changing view angle as seen by the ground station. Because of the generous link margins afforded by the relatively short slant range, the signal should be very strong except when in a fade.

AMSAT FOX-1 Downlink Budget (baseline)
KA9Q, Fall 2013

400		mW	TX power
2000		km	Range
145		Mhz	Frequency
0		dB	Tx losses
0		dBi	Tx gain (average)
0		dB	Rx losses
0		dBi	Rx gain
2000		K	Noise T
2.07	=B28/(B6*1000000)	m	wavelength
-3.98	=10*LOG10(B4)-30	dBW	Tx Power
-3.98	=B16+B8-ABS(B7)	dBW	EIRP
141.7	=20*LOG10(4*PI()*B5*1000/B15)	dB	Path Loss
-145.68	=B17-ABS(B18)	dBW	Rx dens
-145.68	=B19+B11-ABS(B10)	dBW	Rx Power
-195.59	=10*LOG10(B27*B12)	dBW / Hz	Rx N0
49.92	=B20-B21	dB	P / N0
15000	15000	Hz	Bandwidth
8.15	=B22-10*LOG10(B23)	dB	IF SNR
1.38E-23		J/K	Boltzmann k
299792458		m/s	Speed of light c

FOX-1 downlink spreadsheet summary

Random bit errors are characteristic of weak signal systems, such as a high-altitude satellite where the primary impairment is thermal noise. These sorts of systems are modeled as channels with additive white gaussian noise (AWGN). The errors are distributed randomly with respect to time. Convolutional encoders are customarily used in such applications because they are a good solution for the detection and correction of random errors. The conventional choice of forward error correction (FEC) for the AWGN satellite channel is convolutional coding with Viterbi decoding.

For a channel that has slow deep fades, but is otherwise strong, the conventional choice is Reed-Solomon block coding. Reed-Solomon codes don't perform as well as convolutional codes when dealing with random bit error patterns, and convolutional codes don't handle deep fades as well as Reed-Solomon.

Sometimes the two can be combined as on AMSAT-OSCAR-40 where both thermal noise and fading due to an asymmetric antenna pattern were serious concerns. That design included two layers of interleaving to mitigate the otherwise harmful effects of fading on convolutional coding.

The error correction code proposed for the FOX-1 low speed telemetry mode is the venerable (255,223) Reed-Solomon (RS) block code over GF(256).[1] Each RS symbol is an 8-bit data byte for which the natural block size is 255 bytes (2040 bits) containing 32 bytes of parity and 223 bytes of data.

RS codes are well suited to fading channels because they can correct a burst of errors up to one half the number of parity symbols long. For FOX-1, this equals 16 bytes in the data-under-voice channel.

A single (255,223) RS frame can tolerate a fade up to 800 milliseconds long in each 12.8 second frame.

A special synchronization byte is sent between RS blocks not only to help the receiver find block boundaries, but also to help avoid the false frame sync that can theoretically occur if the receiver were to rely only on successful RS decoding. This can happen because RS codes are cyclic codes. Cyclic codes have the property that any shift of a valid codeword always forms another valid codeword. Should two consecutive frames contain the same user data, the end of one frame followed immediately by the beginning of the next would produce a valid

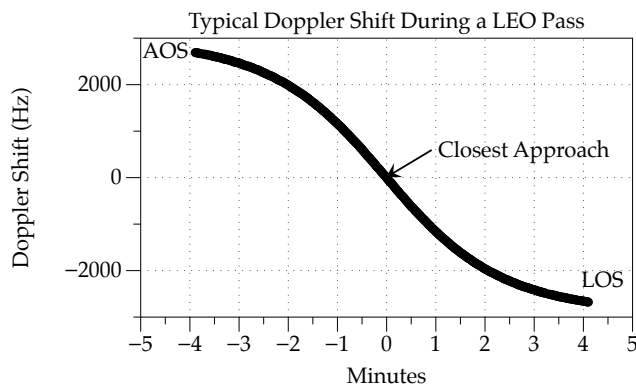
but spurious RS codeword even with incorrect frame alignment. The synchronization byte alleviates this risk.

The false sync problem can also be avoided by “shortening” the RS codeword where the beginning of the data field is padded with zeroes that are not actually transmitted. Shortened RS codes are not cyclic except in the special case where the data is all zeroes. The FOX-1 software team will choose the final RS frame size to fit the “natural” size of a telemetry data frame.

Spectral Shaping

A common problem in many digital transmission channels and storage systems is that they cannot pass or store signals with very low frequency (or DC) components. Typical FM modulators generally cannot create signals with DC or low-frequency components, and typical FM demodulators cannot recreate DC or low-frequency components. These physical limitations are assumed to exist for FOX-1 hardware.

An additional related problem occurs with Doppler shift. When FM is received from a low-altitude satellite like FOX-1, the Doppler shift appears as a low-frequency component on the modulation, almost as if there was a DC offset.

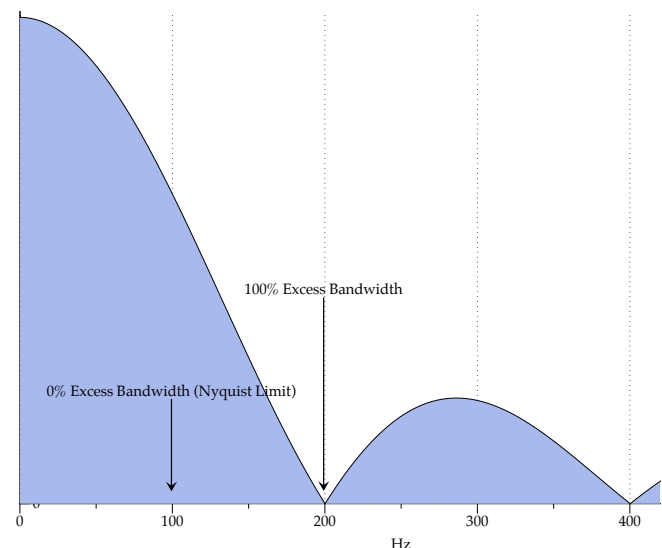


Information in low-frequency components will be lost. Our decoder cannot rely upon low-frequency or DC components. Therefore,

the encoder should eliminate low-frequency or DC components.

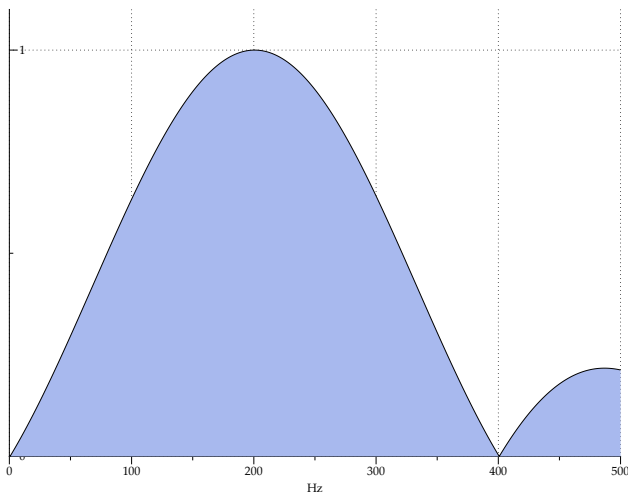
The simplest and most common baseband encoding of a binary digital data signal is the so-called non-return-to-zero (NRZ) format where a logic '1' is encoded as a positive signal and a logic '0' is encoded as a negative signal of the same magnitude (or vice versa). A closely related encoding, familiar to amateurs from its use in the HDLC framing of the AX.25 packet radio standard, is NRZI: a '0' is encoded as a signal change (from - to + or from + to -) and a '1' is encoded as no change.

For both NRZ and NRZI, random data produces a $\sin(x)/x$ (or sinc) shaped spectrum with nulls at multiples of the data rate and a maximum spectral amplitude at DC (0 Hz). This is clearly undesirable.



Unfiltered spectrum of 200 baud NRZ and NRZI codes

The medium speed (9600 bps) FM/FSK modems pioneered by K9NG and G3RUH address this problem with a self-synchronizing scrambler, but it is important to understand that it doesn't really fix the problem. The scrambler will eliminate the even more troublesome spectral line at DC that occurs when the data stream contains



Unfiltered spectrum of 200 baud Manchester code

long constant data strings (NRZ) or long strings of 1's (NRZI), or when the 0's and 1's are otherwise not balanced. The scrambler "whitens" the data, i.e., it looks random, but a random NRZ stream still has a spectral maximum at DC.

Sending a signal with a spectral maximum at DC over a non-DC-coupled channel, like FM, produces a waveform that, in the short term, is no longer symmetric around the time axis. This makes detection less reliable.

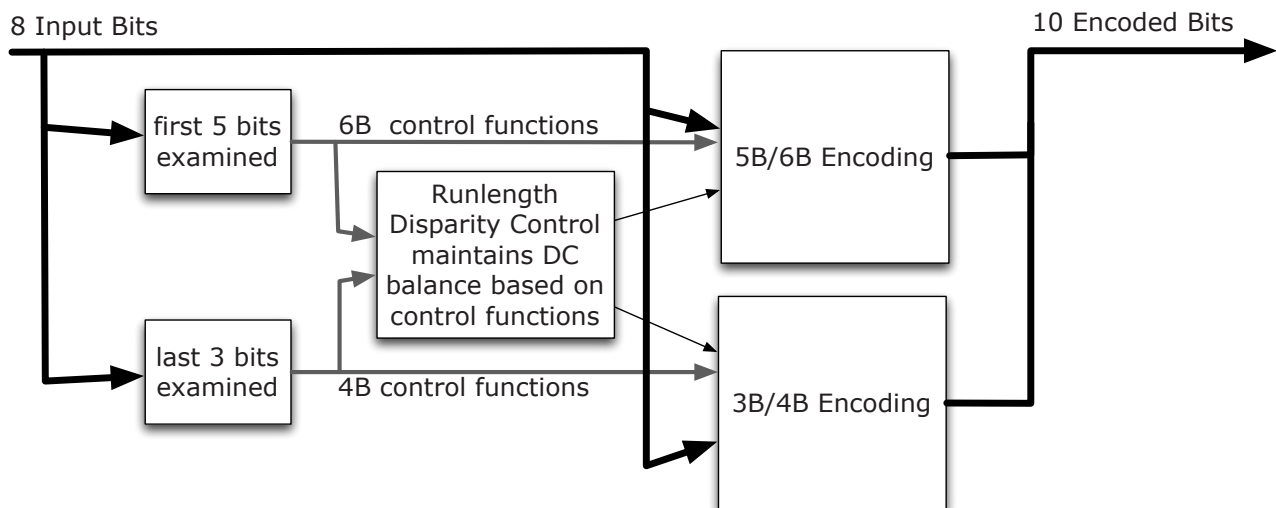
But, there are digital encodings with no DC component regardless of the data sequence, such as the several flavors of Manchester coding. The best known encodes a logic '0'

as one cycle of a square wave at the bit rate and a logic '1' as one cycle of the same square wave with opposite polarity. That is, a '0' might become '01' while a '1' would become '10'. This completely eliminates DC and greatly reduces low frequency components at the cost of doubling the total signal bandwidth. Peak spectral density now occurs at the data rate (where NRZ/I has a null) with the first null occurring at twice the data rate. This method was used in the AMSAT Phase III 400 bps telemetry system.

It seems like there should be a better way, and indeed there is. The specific method chosen for FOX-1 was suggested by Tony Monteiro, AA2TX. It is called 8b10b coding.

8b10b Line Coding

In 8b10b coding, 8-bit groups of data bits are turned into 10-bit groups of channel bits with a lookup table and a 1-bit memory. The tables and rules were chosen so that regardless of the data the channel always contains an equal number of 0's and 1's over the long term. In other words, it is DC-free. No 20-bit channel sequence contains more than two extra 1's or 0's, minimizing low frequency components. And there are never more than



8b10b coding block diagram

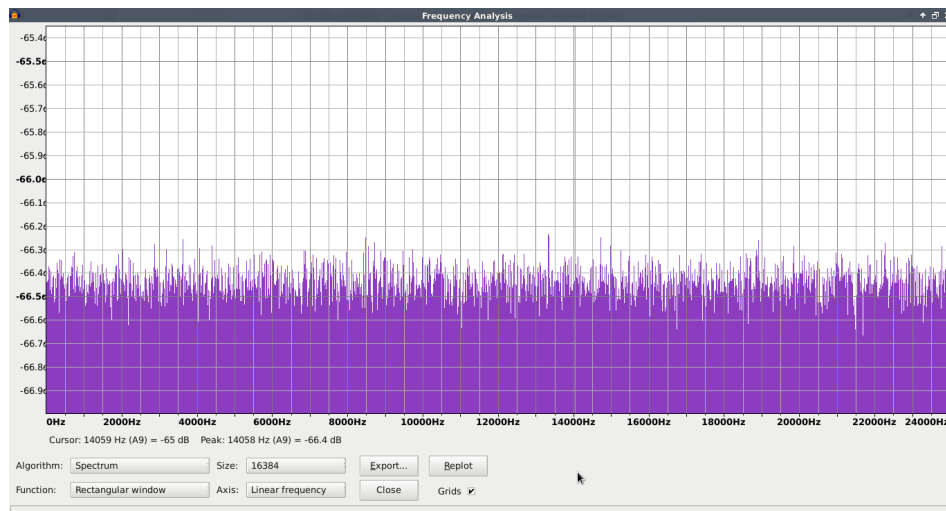
five 0's or 1's in a row so that transitions are frequent enough to maintain receiver timing synchronization -- a function otherwise provided by scrambling or bit-stuffing. Though more complex than Manchester, the spectral overhead of 8b10b is only 20% vs 50% for Manchester.

The 8b10b code sees widespread use in modern digital interfaces and storage from the old DAT (Digital Audio Tape) through Serial ATA, Firewire 800, USB 3.0, PCI Express 2.0 and the HDMI/DVI digital video interface and many more.

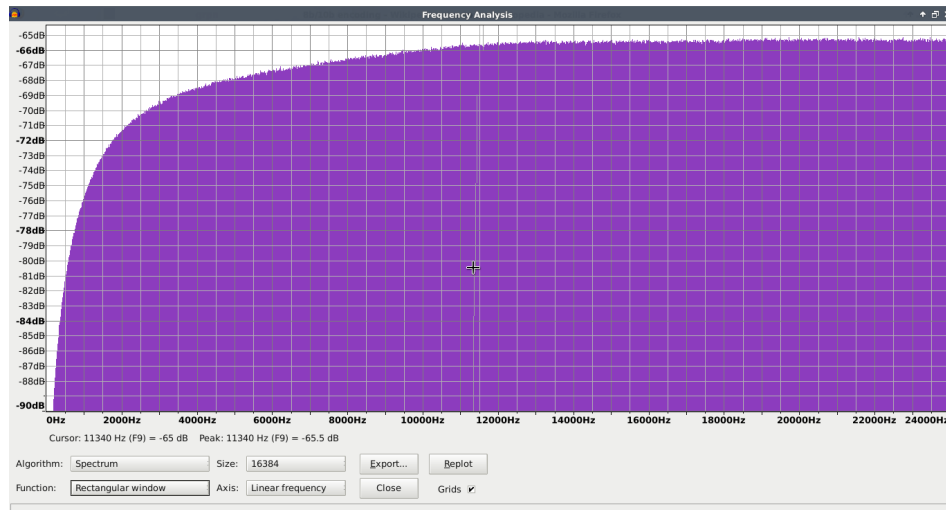
In 8b10b coding, each 8-bit data byte is divided into 5- and 3-bit components that become 4-bit and 6-bit channel sequences. About half of the component values are

assigned a single channel sequence while the rest are assigned two, with the one chosen to meet the overall balance and run-length rules. This is done with the help of a 1-bit Runlength Disparity (RD) memory bit.

The effect of 8b10b coding on the spectrum of a random bit stream can be seen in the following figures. Produced with Audacity, the first is of a random bit stream. The second is of an 8b10b encoded random bit stream. The sample rate is defined at 48kHz. Therefore, the Nyquist rate is 24kHz. Because the data is taken at the sampling rate for the random bit stream, the spectrum appears flat. Had it been stretched to some number of samples per data bit to produce an NRZ waveform, then a sinc-shaped spectrum would emerge.



unfiltered NRZ spectrum, random data



unfiltered 8b10b spectrum, random data

Testing the All-Zeroes Case

It's generally a good idea to check the spectrum of the signal when all-zeroes are transmitted in order to test whether or not there are spectral problems. All-zeroes are often sent when there is no data to transmit. Since this is a data pattern that an operator is likely to encounter, there was interest in whether or not an operator could hear or be bothered by the sound of the telemetry signal.

Because the codeword repeats every 10 samples, the spectral peaks repeat every $F_s/10$. In this simulation, $F_s = 48\text{kHz}$. As expected, the peaks are every 4.8kHz with no DC component.

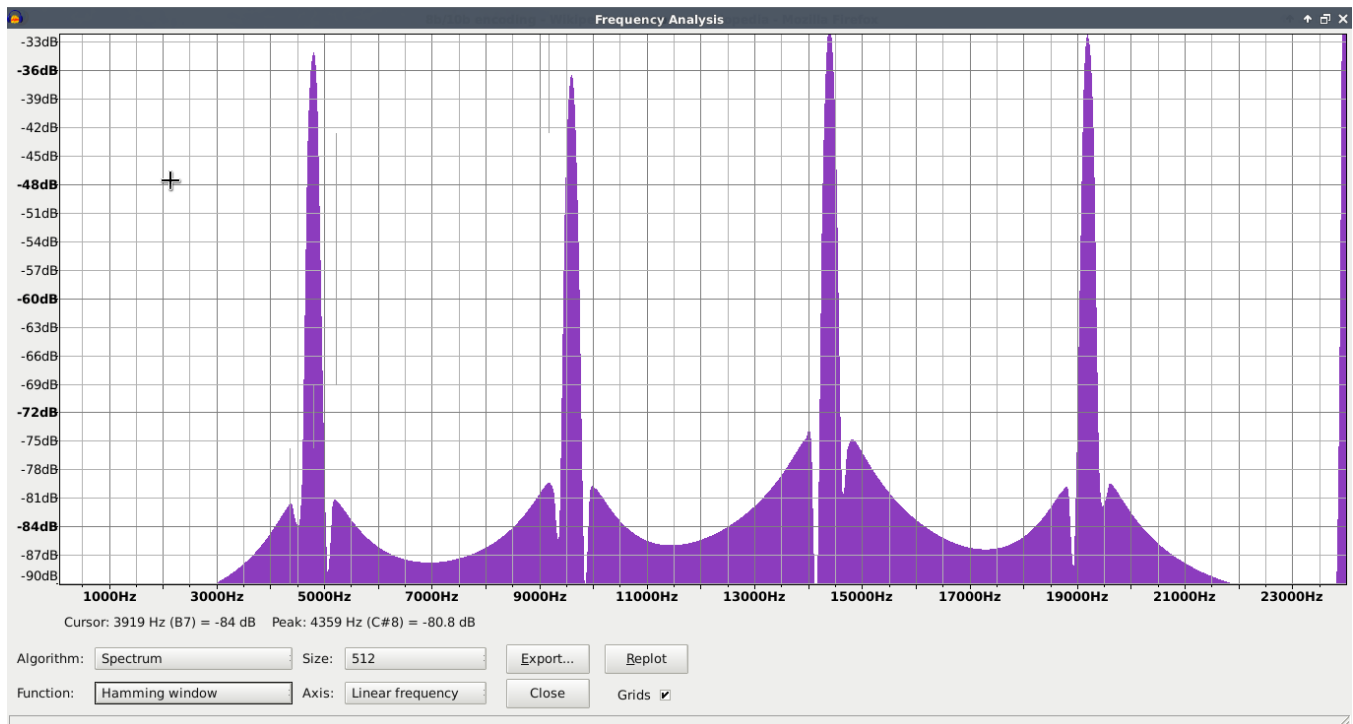
Decoding 8b10b

Encoding 8b10b is straightforward, as it is accomplished with lookup tables. Decoding it is somewhat trickier, and there doesn't seem to be much in the literature about how to do it well.

One way is to build an inverse lookup table to map each 10-bit channel sequence back to a 8-bit data sequence. Invalid 10-bit sequences are flagged as 'erasures' to assist the Reed-Solomon decoder. Helping the Reed-Solomon decoder in this way, by giving it the location of the error, grants us a significant advantage.

When the error locations in a Reed-Solomon codeword are unknown, the decoder can correct up to half as many symbols in error as there are parity symbols. For our (255,223) code with 32 parity bytes, we can correct up to 16 bytes in error anywhere in the codeword. But we can do better when at least some of the error locations are known. Up to twice as better, in fact. If we know where every error is located, we can correct as many errors as we have parity symbols. But, that leaves no additional detection margin. We are at the limit of detection, and have to be certain that none remain.

This works, but we can do even better. Recall that some 8-bit data values have more than one 10-bit channel sequence. The encoder can't just pick at random, though, it must



unfiltered 8b10b spectrum, all 0's data

use the one that meets the bit-balance rules. That's the reason for the runlength disparity control block in the encoder. It has one bit of memory that keeps track of which way the balance needs to be guided in order to balance the number of zeroes and ones. The receiver can detect more errors, and better help the RS decoder, by rejecting those 10-bit sequences that cannot legally follow the previous 10-bit sequence because they would violate the bit-balance rules.

Since we don't know in advance which codeword the runlength disparity control block chose during the encoding, the best method is to try both branches and see which decoded stream complies with bit-balancing. In other words, we test both codewords and go with the branch that has better statistics.

This is essentially what the Viterbi decoding algorithm does. Although best known for convolutional decoding, the Viterbi algorithm can be used to deduce the most likely hidden internal state of a system from its externally visible clues, even when noise corrupts some of those clues.

Because the 8b10b encoder has only one bit of hidden state (the RD bit), compared with 7 or more in a convolutional encoder, this is actually pretty easy. Tentatively decode a series of 10-bit channel words, first by assuming the RD bit starts at +1 and again assuming it starts at -1. See which assumption produces a greater number of successful decodings. With that assumption, commit the oldest word in the sequence, slide the observation window one word forward, and repeat the process.

Control Words and Synchronization

The 8b10b code provides another useful feature: control words. Because 10 bits are used to encode only 8 data bits, usable 10-bit patterns are left over that can be used as out-of-band control words. Up to 12 of these control words can be used, but by carefully restricting their use some very desirable properties can be had. One is the "comma symbol", a unique sequence that cannot be found in any stream of encoded bits, even when word framing is unknown, except when a certain control word is sent. This word is used after each Reed-Solomon frame to provide a way for the receiver to synchronize to frame boundaries.

It can also be used to synchronize the receiver to 8b10b boundaries (since frame sync implies word sync) but an easier way is to examine a sliding window of channel bits looking for the phasing that results in the fewest number of invalid (erased) data bytes.

[1] GF stands for Galois Field, a finite collection of mathematical symbols or objects that is closed under addition and multiplication. These fields enable computations in many different applications. Named for Évariste Galois, a mathematician 1811-1832. He died in a duel.

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Michelle Thompson W5NYV	w5nyv@yahoo.com

The FOX-1 IHU and Telemetry Simulator

or

Making Good Use of Cheap Evaluation Boards

Burns Fisher
W2BFJ

Abstract

This paper describes a printed circuit board initially designed by the author to eliminate some of the error-prone and clutter-prone jumper and breadboard hardware arrangements that the Fox-1 software team was becoming increasingly dependent on. The initial idea was to provide a motherboard which would provide a place to “plug in” a processor evaluation board as well some of the most important components that were to be on a “real” Fox-1 IHU (Internal Housekeeping Unit) board. As time went on, though, circumstances dictated that the board should turn into more of a general purpose IHU simulator.

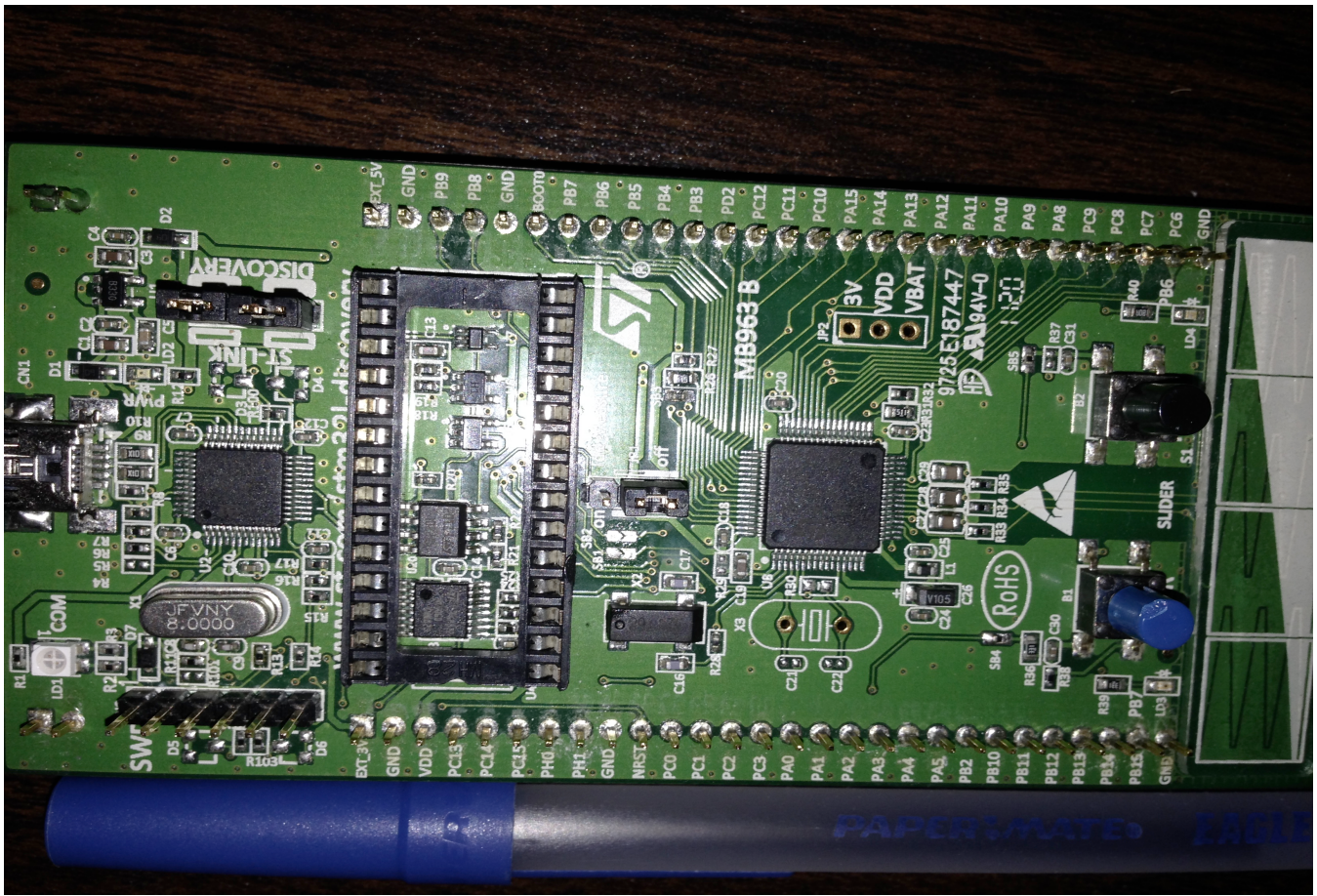
While the board described in this paper is specific to the Fox-1 satellite, the technique is quite general. Manufacturers provide inexpensive evaluation boards for many kinds of processors and other components. These evaluation boards can be incorporated into a project using this “motherboard” technique with much less design, expense, and surface-mount soldering expertise than would otherwise be required.

Some of this paper may be more interesting to those who have had little experience in designing and building printed circuit boards (which was me before this project!) than to those who are already experts.

Genesis of the IHU Simulator

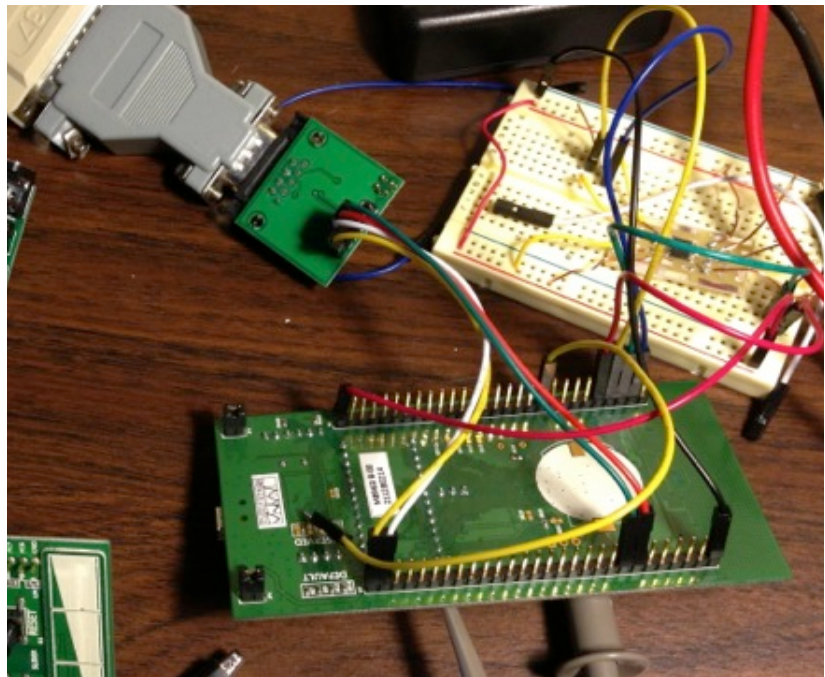
The Software Development Board

The Fox-1 IHU will be built around an STM32L151 microprocessor control unit (MCU), which consists of an ARM Cortex M3 CPU core, flash program memory, RAM, A/D and D/A converters, SPI, I2C, and USB bus controllers, serial ports, and a number of general-purpose I/O pins. The Fox-1 software team, of which the author is a member, started developing the basic software framework on an “STM32L1xx Discovery” board. This \$15 board, in addition to an MCU, holds a crystal oscillator clock, a USB-based means of programming and debugging, a power converter from the +5V USB input to +3V, some LEDs, some buttons, and importantly, 56 header pins to allow access to many of the processor pins as well as the 3V regulator output. The Discovery board’s low cost made it possible for each software developer to have a processor to work on locally.



STM32L1xx Discovery Board 1

It was not long before we started to make connections to the Discovery header pins with jumper wires and to hang additional components on the jumpers. The first was a set of jumpers from the processor's CMOS serial port to a level-converter and then to a computer's RS-232 serial port so that we could get text into and out of the system. As we started writing drivers, we needed to connect an SPI-bus memory peripheral (the "F-RAM"), thermal sensors and audio input/output for the A/D and D/A converters, and I2C bus peripherals. We built up quite a rat's nest of fairly fragile wiring, Radio Shack solderless breadboards and components. We ended up spending some of our development time debugging



The Rat's Nest 1

We ended up spending some of our development time debugging

wires that had fallen off or broken. Probably worse, each developer had a different and inconsistent setup reflecting the drivers or other modules that he was working on.

The straw that broke the camel's back for me was the need to connect two Discovery boards with an I2C bus. Bill Reed, NX5R, had such a setup for developing the I2C drivers, and would soon need more components. Mike McCann, KB2FMG, and Jonathan Brandenburg, KF5IDY, were also getting more and more complex setups. I started thinking about an easy way to connect up everything quickly and neatly and with less pin counting. My first thought was ribbon cables that could plug into the two 28-pin headers on the Discovery board, but what about the other end? Eventually I came up with the idea of building a motherboard with sockets for the headers on two Discovery boards, an F-RAM chip, and maybe an RS232 level converter. I called this the "Fox-1 software development board" but the name was about all that I achieved this time. It went on the back burner as other projects and Fox software components intervened.

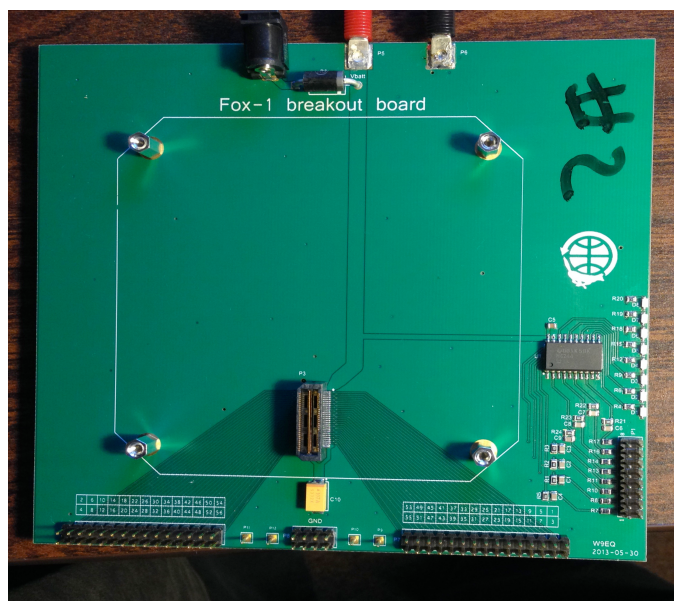
Necessity is the Mother of the Motherboard

Aside from the rat's nest problem, things were going pretty well for the software team in May 2013. We had the first actual prototype IHU card, Version 1, Serial Number 1, designed and built by Bdale Garbee, KB0G. This IHU card ran the software very well, and we displayed it transmitting a voice ID at Hamvention. In addition, the promise of more of these boards arriving reduced the need for the software development board.

But then disaster struck: The Black Forest Fire of 2013 burned thousands of acres in Colorado and consumed over 500 homes, including KB0G's. The human consequences of this disaster are terrible (at least two lives lost, thousands of people affected for years to come).¹ While the most serious toll of the fire was human, one small consequence was that all the un-built Fox-1 IHU Version 1 boards along with the components that would have been used to build them were lost. Suddenly the software development board seemed to be back on the table.

The IHU Simulator Is Born

We already had some white-wire ECOs on IHU V1 and additional design changes affecting the IHU were coming. Fox-1 chief engineer Tony Monteiro, AA2TX, hoped to avoid the expense of a V3. That implied no additional IHU prototypes for a while. This lack of boards would cause some issues not only for the software team but also for integration testing as other Fox-1 prototype boards appeared. The answer appeared in a light bulb when AA2TX described to me a breakout board that was being designed for the Fox-1 satellite bus.



¹ Appendix A lists groups that accept donations for victims and first responders.

The breakout board has two headers set up to allow test points on the satellite bus, along with satellite bus connectors on either side. These connectors allowed other Fox-1 boards to be stacked on the breakout and signals accessed for testing. It occurred to me that I could build the software development board with headers that matched the breakout board, and connect them with ribbon cables. Even better, I could assign many of the processor pins to their correct satellite bus pins and be able to test parts of the integrated satellite before the real IHU appeared. Voila! An IHU simulator!

Designing The IHU Simulator

The Requirements

The original Fox-1 design called for STM32L151 processors on the PSU and Battery boards as well as on the IHU. To code and test interactions between pairs of processors, I started with the idea of designing room for two Discovery cards with an I2C bus connecting them. In other words, we would partially simulate a PSU or a Battery card as well as the IHU. The simulator would also contain an F-RAM chip and connectors for a ribbon cable. Further, I wanted to be able to power the board either from the same wall transformer that powers the Fox breakout board, or from connecting the USB programming cable to a Discovery board. And what the heck, I might as well put a USB connector on the simulator to act as the Fox umbilical and allow the board to be powered from that USB plug as well. This led to a number of jumpers and a diode to define where the +5V power was coming from (only 1 source at a time!). The +3V required by other components comes from the Discovery board itself (remember it has a power converter built in).

For data busses, the simulator needed to provide pull-up resistors for the I2C bus and to connect I2C to the satellite bus and to the two Discovery boards. The F-RAM on the board is a slave on the SPI bus.

Some other requirements involved debugging: I included 8 LEDs and many ground and +3 pins all of which can be jumpered to satellite bus pins or Discovery pins. These allow us visually to check logic signals (for example 'transmitter on') or manually to connect logic levels to sensors (for example 'receive antenna deployed'). I also designed in a couple of potentiometers, which would produce a variable voltage input for the Discovery analog-to-digital converters. It turns out that we have not yet built any boards with pots installed.

One requirement was removed by NX5R's fortuitous find of a cable with a USB plug on one end, a serial port simulator built in, and female header pins with CMOS logic levels on the other end. (Search for PL2303HX on Amazon or EBay). This device completely removes the need for a CMOS/RS232 level converter. It looks like a serial port to the computer, and we can connect it directly to header pins on the simulator board (taping up the red +5 wire).

The last requirement came late: The decision was made not to use an MCU to generate telemetry on the Battery card, but rather an I2C-based analog-to-digital converter chip. This led me to design a location for two of these chips (along with address jumpers) and to extend the I2C bus so that programmers could work on the A/D chip before the battery card was available.

Tools

A recent technical article introduced me to a tool called ExpressPCB to design printed circuit boards. The author had made his own masks and etched his own board. Doing my own etching did not interest me, but the tool seemed worth a look. It turns out that there is a pair of tools, ExpressSCH and ExpressPCB, with which you can draw schematics, and then design a matching printed circuit board. You can also send the design over the Internet for the board to be built. The tools are available at <http://expresspcb.com>. ExpressSCH and ExpressPCB are free, and while they do a good job, they are limited. A few more tools helped a great deal.

You can print your schematic or PCB design, but you cannot output a PDF file; that missing feature makes it harder to share your design or have it reviewed. CutePDF Writer (<http://cutepdf.com>) is a great free tool that looks to Windows like a printer. You just “print” your design or schematic, and it turns into a PDF.

The “Express” tools come with a library of component templates, but of course they never have exactly the one you want. There are many more available at the ExpressPCB Yahoo group. You do have to join the group (and get a Yahoo account) in order to download their library files, but all of these things are free.

Although the “Express” tools help you a bit to make sure the board is designed to match the schematic, that help is limited. It consists of matching the components on the PCB to those on the schematic and then highlighting the pins that are on the same net (i.e. need to be connected together). However an ExpressPCB Yahoo group member wrote a wonderful tool called xCheck (www.softpedia.com/get/Science-CAD/xCheck.shtml). This tool compares all the nets on the schematic to the traces on the PCB design and among other things, will tell you if there are missing or extra connections. It truly saved this board from being a total mess.

And finally, although I am mainly a Linux user now, and these tools run on Windows, the free virtual machine monitor “Virtual Box” from Oracle (<http://virtualbox.org>) enabled me to use my Linux machine running Windows in a virtual machine. You do need a Windows kit and license, though.

The Design

It is unnecessary to go through all the trials and tribulations of drawing the circuit diagram. Anyone else who has done this understands. However, a few ‘mechanical’ hints may be useful.

First, ExpressPCB and ExpressSCH require that each device have numbered (no letters) pins, although the pin numbers can be hidden on the schematic and the PCB silkscreen. Labels can also be added. For the Discovery board sockets, I hid ExpressSCH’s notion of pin numbers and substituted as labels the names of the pins on the Discovery board, which in turn matched the names of the General Purpose I/O devices in the code (for example B2, C7, etc.). With a similar technique, I labeled the pins on the ribbon cable connectors to match the satellite bus pins that they would connect to. Thus I could use the Fox satellite bus and MCU definitions as the basis for a table of ribbon-to-Discovery connections (see Appendix B). Care is required to match the labels to the same pin number between ExpressSCH and ExpressPCB.

Next, ExpressPCB does not have any automatic routing software, nor could I find any ‘add-ons’, so I had to do the routing myself. A general guideline for a two-sided board, which I found on the web frequently, is to place the horizontal traces on one side and the vertical traces on the other side. (For a 4-layered board, do the same, but with power and ground on the other two layers.) I did use a two-layer board, and this technique worked very well! At first I tried to avoid vias (connections between layers), but they do not add cost with ExpressPCB, and I found no guideline that suggested avoiding them. After a while I stopped worrying and things got even easier.

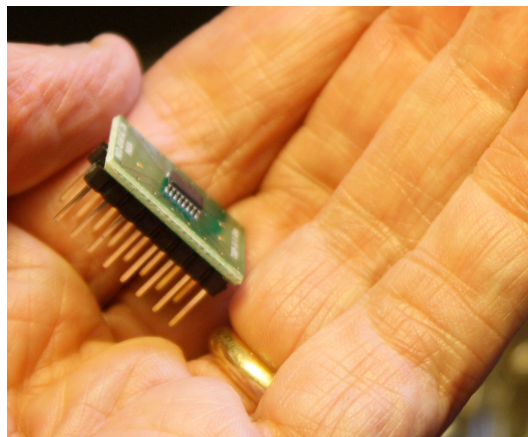
As discussed earlier, ExpressPCB can read an ExpressSCH schematic, match up the components and give you an indication of which pins must be connected. For example, if you click on one pin, all the pins it should be connected to are highlighted. This feature is very worthwhile; it is worth the trouble of making sure that the component names and pin numbers all match between SCH and PCB. I went through each pin on each component and drew traces to make the connections.

Something that I found surprising while doing the routing is that there is plenty of room to route a signal trace between two pins in a .1” connector. It was even easy to solder the pins without shorts in the final product! However, when there are several components close to each other, each with many pins (such as the Discovery board and the ribbon cable connector) you must leave extra room between components for all the signal lines that have to pass parallel to each other and between the components. (See the PCB layout in Appendix D between J1/J2 and B1, for example). I also reduced the size of vias from the default to allow traces to be a bit closer together in these tight spots.

I also used a ground plane on the bottom of the board. It may have been unnecessary at these low frequencies, but it seemed like a good idea. However, in places with many “wires” I ended up with ground plane sections that were not cut off from the rest of the ground plane. That seemed bad, so I eliminated the ground plane in locations where there were many wires. (Again, see the layout in the same location mentioned above.)

Components

Since I had no tools for and no experience with surface mount technology, I designed the boards with through-the-hole components wherever I could. This was no problem with resistors, capacitors, diodes, headers, and sockets. However, there were two components that are only available in surface mount: The F-RAM and the ADS7828 A/D converter. The F-RAM chip was actually large enough for me to solder with traditional techniques, although it was pretty much at the limit of my capability. The A/D chip was smaller and with twice as many pins. There was no way could I hand solder that. KB2FMG came to the rescue by discovering a company called Proto Advantage (www.protoadvantage.com) which would solder surface-mount chips on a small adapter board with DIP pins on the bottom. These could be used in a socket or soldered through-the-hole. It was a great find!



Check, Double Check, Triple Check

I cannot emphasize enough that you should recheck over and over even when you think you are done. I must have gone over the connections 5 or 10 times, and as you will see I still had a few bugs.

First I checked the labels on each Discover pin to be sure that they matched the labels on the physical board. I checked the pin labels on the ribbon cable header to be sure that they matched the satellite bus labels on the breakout board. I checked the official ExpressXXX pin numbers between SCH and PCB to be sure that they matched the labels.

Next, I checked each line on my Discovery-to-satellite bus table (Appendix B) to be sure that it matched the connections on the PCB design. Here is one time that hiding the pin numbers and using labels had me at a disadvantage. It is possible to print out all the connections (nets) with xCheck. However, they are listed by pin number, not by label. That is not very helpful for checking.

Another check is to select each pin and let ExpressPCB highlight all the other pins it should be connected to. Trace the connections to be sure that you have reached all the pins.

Finally, I the xCheck tool, mentioned above. xCheck looks at all of the pins on all of the components in the schematic and figures out all the connections that should be made to them. Then it looks at the PCB and confirms that all the connections that it has found are made, that there are no connections made that it does not know about, and that all pins on all devices are connected. For that reason, it provides special schematic symbols to mark pins that you intend to leave unconnected. You can see the little “x” markings on unused pins in the schematic in Appendix C. It also checks “design rules”. For example, are two traces too close to each other, or is something too close to the edge of the board? This is a fabulous tool! It found more problems than my entire set of manual checks put together. Again, the extra work of using the “no connection” symbols and making sure names match correctly is very worthwhile so that this tool works correctly and cleanly.

For each checking/fixing pass I made, I found a few more errors. On one of the first passes, I discovered that the two ribbon cable connectors were reversed top and bottom. On another pass, xCheck discovered that when I changed those cable connectors and rerouted the signals, I had managed to cross two traces on the same side of the board! (xCheck considered this to be connecting two nets together). xCheck also found a few traces that might have come close enough to connect to the right pin, but that connection was not explicit in the board description data. I don't know what would have happened during board manufacturing.

Finally the day came when I got through all my checks without finding any problems. I put everything aside, and came back a day or two later and checked again. (I probably found something else...)

Pulling the trigger

Finally, I decided that the time had come to ship my design off to ExpressPCB to have the boards built. I pushed the button on the app and got the usual series of questions. Except that THESE questions made a big difference in price!

Do you want silkscreen? You mean you have to pay EXTRA for getting the board labeled? I had carefully drawn a lot of stuff that would help builders and users, but silkscreen was pretty expensive, so I backed off and changed some of the silkscreen to copper traces.

Do you want a solder mask? I thought this was the stencil that you use to put on solder paste for reflow soldering. I was not going to use that, so I said no. Luckily, telephoned AA2TX for moral support, and he told me that the solder mask is the green solder-resistant film that covers the board except for where you are soldering, and keeps you from getting solder all over the place. He told me it would be REALLY hard to solder without. Ok...I said yes to the solder mask. And that actually came together with the silkscreen, so I went back and removed my copper letters and numbers.

I finally completed everything, looked at the price and gulped, pushed the final button to send off the shipped off the design, and waited.

The Finale

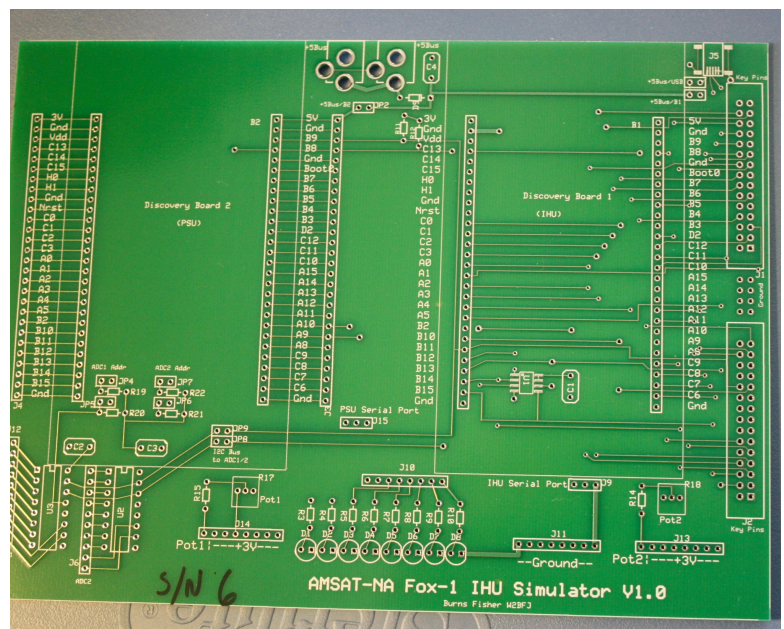
Hey la-day-la, my boards are back

The boards finally arrived by UPS about a week later. They were absolutely beautiful. The company had done a fantastic job! In the meantime I had written a test plan of sorts (Make sure +5 and ground are not shorted; make sure +5 has the correct polarity; make sure +3 gets to the F-RAM and ADS7828 in the correct polarity. Then test everything else.)

I soldered on a couple of the most critical components (all in accordance with my test plan, of course) and plugged in the power. Voila! It ran; it talked to the F-RAM; it talked to the serial port! Time to finish building S/N #1, and then build the rest!

Bugs, Solutions, and Lessons Learned

While installing the components, I found three “design bugs.” I just totally messed up and never noticed these problems despite all my checking. I found another bug later that was due to my misunderstanding the Fox bus spec. And a few later board ECOs were required because of



changes to the bus spec after the simulator was built. I'm going to detail the "totally messed up" bugs since they have lessons to teach.

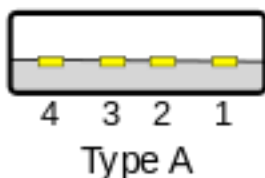
1. Hole sizes. Note to self: Not all components have the same lead sizes! When I placed the holes for header pins, I simply edited the ribbon cable connectors (which had the spacing I required). The ribbon cable connector pads had holes of $.029 \pm .004$, and the connectors fit fine. However, the header pin size was $.025 \pm .004$. Notice the overlapping tolerances. Oops. The headers would not go into the hole. Usually I could solve this by pressing the headers into the holes with pliers, but for headers with more than 2 or 3 pins, I needed to grind them down a bit. Not a disaster, but it took time, and I lost a few headers to over-grinding.

Lesson: Those mechanical specs that we often ignore for home projects can be REALLY important!

2. Physical component sizes. The ExpressPCB component library was pretty good at showing the outlines of parts. However, the Proto Advantage 16-pin DIP adapter was NOT the size of an actual 16-pin DIP component. It was noticeably larger. Luckily, I had placed the two DIP pads far enough apart to fit. Unluckily, one of them was too close to the header that I had designed for making connections to it (see J6 and U2 on the PCB layout in Appendix D). For now, we are not using the header and the A/D chip that are too close together. If a second one is needed later, we could solder in some wires where the header was supposed to go. Again, not a disaster, but a reduction in functionality.

Lesson: Pay attention to outline dimensions too. Don't just assume that the library components are correct.

3. Read the diagram right. Try looking up the wiring diagram of a USB connector and you will find something like this:



You may have guessed the issue. Are we looking at the male or the female connector, and are we looking at the connector itself or at the solder pins? I thought I knew. I thought I triple checked. But I was wrong. I had the connections to the USB connector pad mirror-imaged. It was not fixable. I just filled the USB connector I had soldered on with hot-glue and never installed the rest.

Lesson: Triple checking is not always good enough if you are checking against your own prejudices! Compare with a known-good installation of a similar type. Use an ohmmeter. Invent your own technique!

I won't go through the other problems and fixes in any detail.

They all involve having to connect a different Discovery pin to a different bus pin, and mostly picky errors, misunderstandings, or actual changes to the spec. Besides a soldering iron, an X-ACTO knife, some fine wire (I used #30 wire-wrap wire), and a bit

of hot glue to hold it all together mechanically works wonders. The lesson to be learned here is simply that for a board of any complexity at all you WILL have to do some modifications after the board is built. Don't kick yourself about it. Just expect it, sigh, and make the modifications.

Using The Simulator

I built the first board, KB2FMG the second, and then I built the other four. We now have 6 simulator boards and 4 breakout boards (which connect the simulator to the satellite bus), and as I write this we have one prototype experiment board and expect other prototype satellite boards soon. Several of us are using the simulator standalone to give easy access to the A/D converter chip, and the F-RAM, as well as other signals and grounds. The worst bugs on the board have turned out to be not serious impediments to its use.

We intend to use the simulator board at least to debug software's interaction with the RF, Battery, PSU, and experiment boards (pair integration testing). Whether we will use the simulator for larger integration testing remains to be seen.

Final Thoughts

This technique could be useful for future satellites, although we all hope that a disaster like the Black Forest fire would not play into the decision.

I also have ideas for several projects in my shack and my home that I might base on an evaluation board like the Discovery using this technique.

If I were to design another board through ExpressPCB, I would use a great deal of care to try to reduce the size either to exactly 3.8"x2.5" (\$51 for 3 boards) or to keep the size under 21 square inches (\$166 for 6 boards). Larger boards have a significant setup cost, a tiny per-board charge, and a moderate cost per square inch. One way to save considerable size would be to use ribbon cables to connect the evaluation board to the PC board rather than providing the (mostly unused) square inches to mount it. Digikey (and probably Mouser) can build many different sizes of ribbon cable to order quite inexpensively.

APPENDICES

A. Places to Help Black Forest Fire Victims or to Support First Responder Organizations

The following are copied from Bdale and Karen Garbee's web site, www.gag.com.

Pikes Peak Community Foundation Emergency Relief Fund

<http://www.ppcf.org/products/emergency-relief>

Black Forest Fire/Rescue

<http://www.bffire.org/>

Falcon Fire Department

<http://www.falconfirepd.org/community-resources/black-forest-fire-information-20130702152911> (I'm guessing this date will change if there are updates)

B. Part of the Bus Pin/Discovery Pin Table

IHU Simulator Discovery Board and Satellite Bus Pin Assignments 10/03/13 03:57 PM

Pin	Nomenclature	Type	Voltage	Source	Disco Pins on W2BFJ Simulator	Load	Notes	ECOed on S/N
1	SPI1 NSS	Digital	Note ¹	IHU	Not Simulated	EXP 1-4		
2	TX PA Current	Analog	0 - 3.0 V	TX	C2	IHU		
3	SPI1 SCK	Digital	Note ¹	IHU	B13	EXP 1-4		
4	TX Temperature	Analog	100-2000 mV	TX	C3	IHU		
5	SPI1 MISO	Digital	Note ¹	IHU	B14	EXP 1-4		
6	Exp 4 Thermistor	Analog	N/A	Exp4	?????	IHU	ECO?	
7	SPI1 MOSI	Digital	Note ¹	IHU	B15	EXP 1-4		
8	RX Osc Temperature	Analog	100-2000 mV	RX	D2	IHU	ECO req. ADC can't read D2	
9	Serial RXD	Digital	3.0 V	EXP 1-4	A3	IHU		
10	RSSI	Analog	0 - 3 V	RX	C1??	IHU	ECO to C1?	
11	Serial TXD	Digital	3.0 V	IHU	A2	EXP 1-4		
12	IHU Audio 1 Out	Analog	0 - 3 V (audio)	IHU	A5	TX		
13	Experiment Enable 1	Digital		IHU	B5	EXP 1-4		
14	*RESERVED SPECIAL*	Analog	N/A	IHU	Not Simulated	TX		
15	Experiment Enable 2	Digital		IHU	Not Simulated	EXP 2		
16	RX Command Data 0	Digital		RX	C6	IHU		
17	Experiment Enable 3	Digital		IHU	Not Simulated	EXP 3		
18	RX Command Data 1	Digital		RX	C7	IHU		
19	Experiment Enable 4	Digital		IHU	A15	EXP 4	ECOed. Original was B8	3,4,5,6
20	RX Command Data 2	Digital		RX	C8	IHU		
21	*RESERVED*				Unused			
22	RX Command Data 3	Digital		RX	C9	TX		

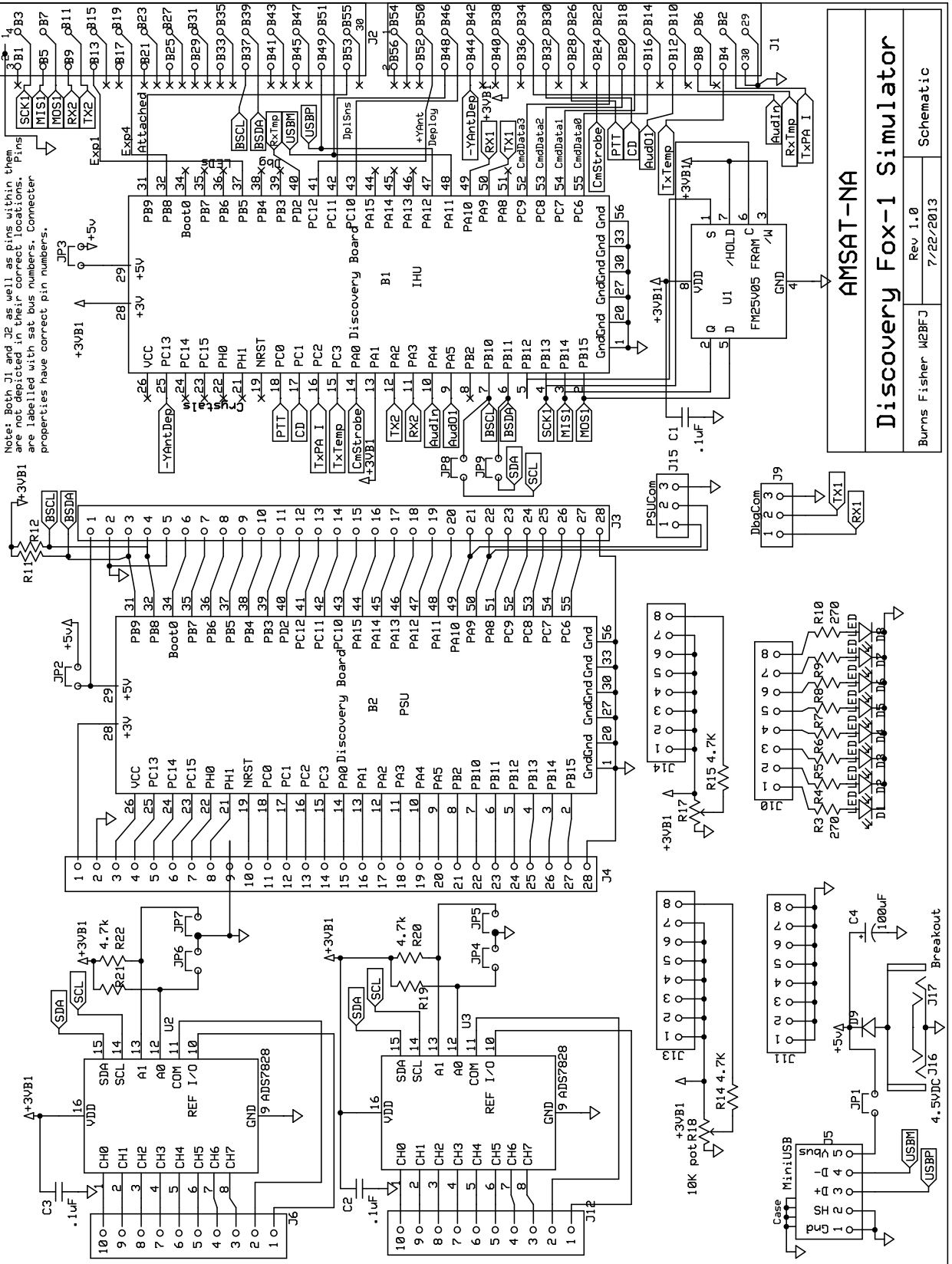
C. IHU Simulator Board Schematic

The schematic and PCB layout is as-built. It does not include later ECOs, so all the problems are right there to see. Notice that I carefully outlined the footprint of the Discovery card, but not of the ADS7828 mounted on the DIP adapter.

D. PCB Layout

The PCB Layout uses colors for different layers. (Yellow is silkscreen, green is bottom, and red is top.) The layout is legible in printed monochrome, but will be clearer in color on the PDF version.

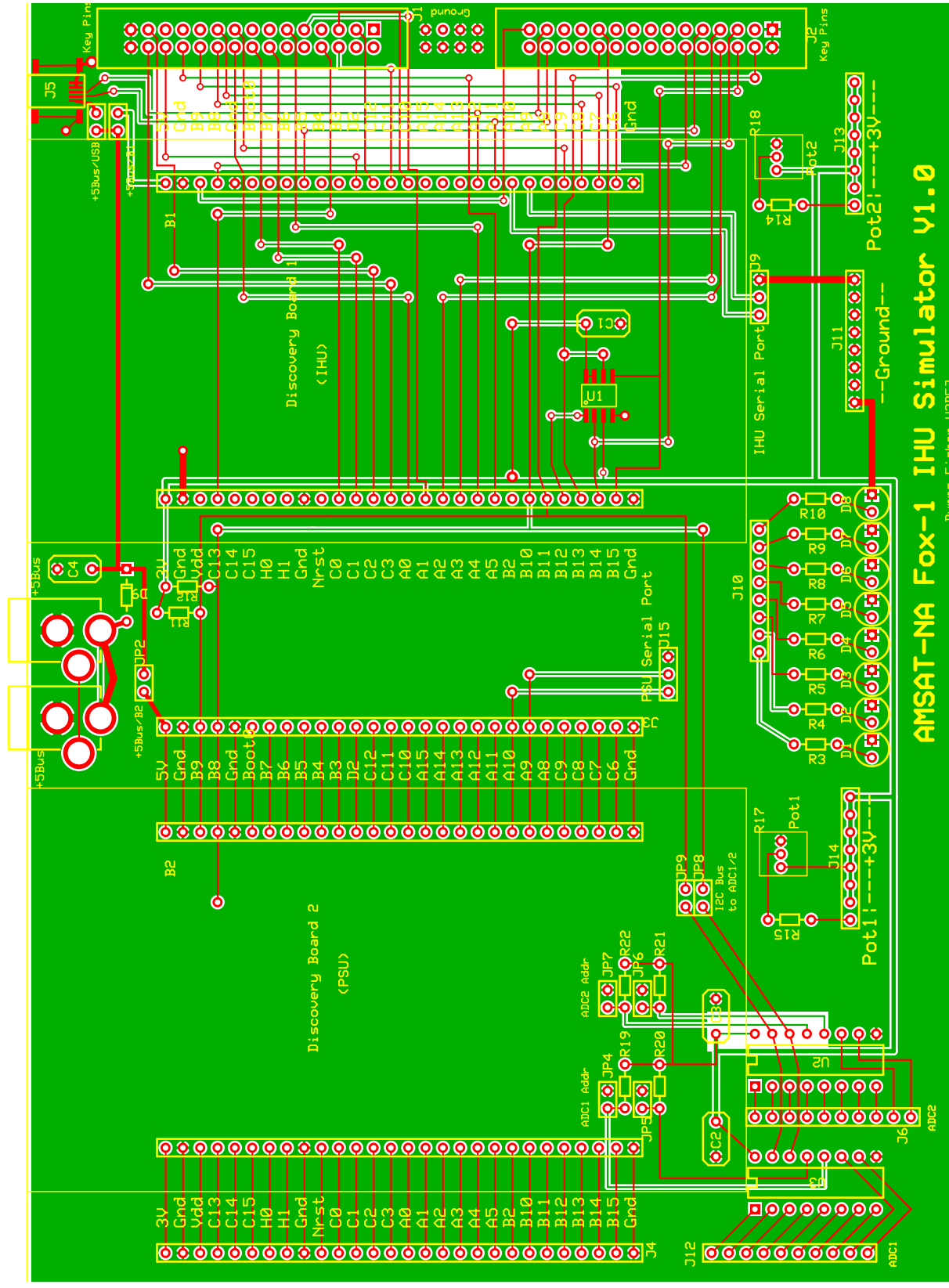
Note: Both J1 and J2 as well as pins within them are not depicted in their correct locations. Pins are labelled with sat bus numbers. Connector properties have correct pin numbers.



AMSAT-NA

Discovery Fox-1 Simulator

Burns Fisher W2BFJ Rev 1.0 7/22/2013 Schematic



Virginia Tech Cubesat Camera for FOX-1

by

Kevin Burns, KJ4SYL
Bill Clark, KK4EWQ
Mitch Davis, WQ3C
Zach Leffke, KJ4QLP

1 Introduction

One of the many goals of AMSAT's Fox-1 Project is to provide experimental payload space so that third parties may gain access to Space. In support of the educational mission of AMSAT in regard to the Fox-1 Project, Virginia Polytechnic Institute & State University (Virginia Tech) has been granted the top two boards in the stack (in the +Z direction) of the Fox-1 spacecraft to fly an experimental imaging experiment. The Virginia Tech team has developed an experimental CMOS camera for this spacecraft that will be capable of taking 640 x 480 resolution JPEG images from orbit and fits on a single cubesat form factor board. These images will then be downloaded from the spacecraft when placed in "high speed" downlink mode to allow Amateur Radio operators around the world to receive the images. On the ground, the decoding software will be capable of reconstructing the images from the downloaded image packets, allowing operators to directly view the image from the data downloaded to their ground stations.

2 Camera Overview

2.1 General Description

When Fox-1 is placed into high speed data mode by commands sent from the control station on the ground, image acquisition and download begins. First the Internal Housekeeping Unit (IHU) powers on the camera by sending an Enable signal on the spacecraft bus to the Experiment 3 card. Commands are then sent from the IHU of the spacecraft to the camera MicroController Unit (MCU) informing it that it is ready to begin image download. The MCU then enables the necessary camera components and sends the proper signals to the camera chip (OmniVision's OV7670) and to the image buffer (AL422B aka FIFO). Pixel data from the camera is stored in the FIFO at high speed. The MCU then pulls pixel data from the FIFO, runs it through the JPEG compression subroutine, and stores the compressed data on the external memory chip (MR25H10). Once the complete image is compressed and stored in the external memory, the MCU then downloads the image chunks to the IHU.

As the IHU receives the compressed image chunks, it includes them into the payload of a properly formatted packet (header, payload, CRC, etc.) then sends the packet to the high speed modulator for transmission to the ground. Once the entire image has been downloaded from the external memory the camera card then begins the process over, starting with a new image acquisition. This process of capturing an image, compressing it, and downloading it then repeats until the IHU receives a command from the ground to exit high speed mode.

2.2 System Block Diagram

A system block diagram is shown below for the general connection of the subsystems that make up the Virginia Tech Cubesat Camera. Other than as noted in the diagram, all components reside on the experiment 3 card. The detailed schematics and board layout can be found in Section 7.

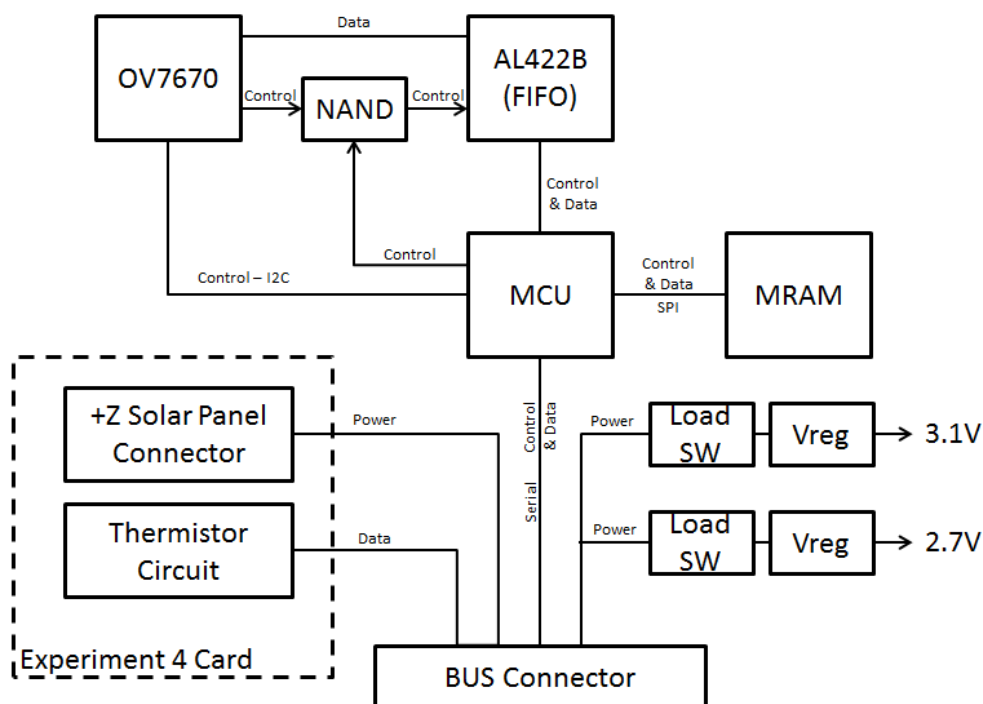


Figure 1: System Block Diagram

2.3 Camera Location

Specifically, the camera and the majority of the electronics reside on the Experiment 3 Card of the Fox-1 spacecraft. This is the second from the top card in the stack in the +Z direction. The Experiment 4 card was also granted to the Virginia Tech team in order to have enough

room for the camera lens mount and lens to protrude. At this time, the Experiment 4 card carries a temperature sensor circuit that is unspecific to the camera experiment. It also contains a feed through connection for the +Z solar panel to the spacecraft power supply board.

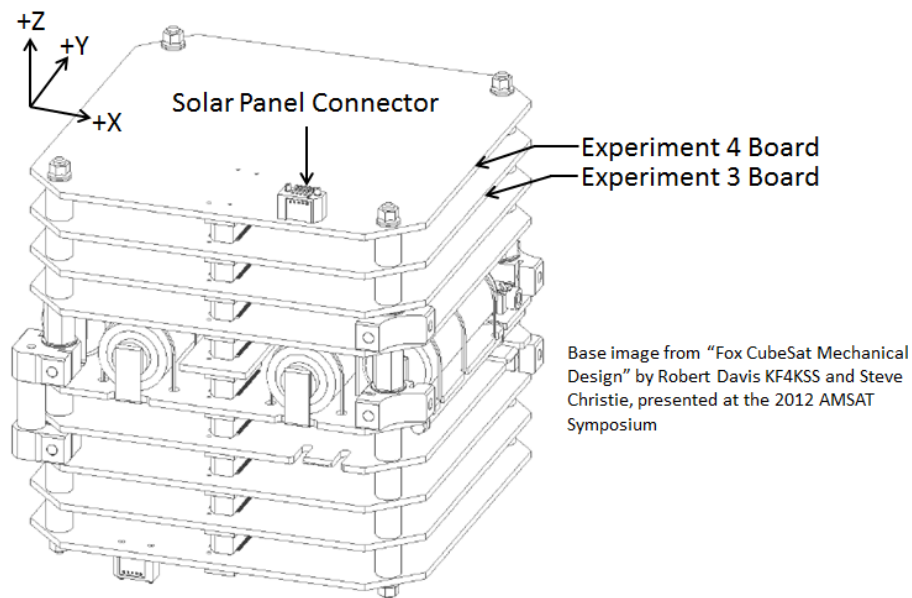


Figure 2: VT Camera Location in Fox-1 Stack.

2.4 Power Consumption

The total orbit average power consumption constraint given by AMSAT to the Virginia Tech team for this project is 250 milliwatts orbit average power consumption. Table 1 below shows the total peak power consumption of the camera board. It should be noted that not all components will be active at any given instant when the camera board is powered on. For example, during the image acquisition process when data is transferred from the OV7670 to the FIFO, the external MRAM memory is not necessary and will be placed in standby mode. This will lower the actual power consumption from the number given in the table below. Additionally, it is known that the camera will not operate at 100% duty cycle in a given orbit, and therefore it is safe to state that the camera will fall well below the power constraint requirement. When the camera experiment is not active (Enable signal from IHU is LOW), the load switches will still be connected to the bus battery pins, but will draw less than $0.27 \mu\text{A}$ apiece.

Table 1: Camera Peak Power Consumption

Component	Operating Voltage	Operating Current	Power Consumption
OV7670	2.7V	22mA	60 mW
NAND	3.1V	10 μ A	0.031 mW
AL422B FIFO	3.1V	33 mA	102.3mW
MCU	3.1V	6.72 mA	20.832 mW
MRAM	3.1V	27 mA	83.7 mW
		TOTAL PEAK:	266.863 mW

2.5 Expected Image Characteristics

The camera sensor selected for this project is the OV7670 from Omnivision. A low profile lens fabricated from glass and aluminum was selected due to the compact dimensions required in the board stack up. A custom lens mount was fabricated from aluminum to allow the proper alignment and mounting of the lens. With all of these factors taken into account the expected field of view for the image sensor is 22.3 degrees along the 640 pixel axis, 16.7 degrees along the 480 pixel axis, and 27.6 degrees along the diagonal of the sensor.

Taking the diagonal field of view of 27.6 degrees and an approximate orbital altitude of 500 km, the expected resolution of the camera will be around 300 meters per pixel *at best*. This calculation assumes Nadir pointing of the spacecraft at the time of image acquisition and does not factor in the JPEG compression. If the spacecraft is tilted away from Nadir and with JPEG compression (20:1 target compression ratio), the actual resolution will be somewhat more degraded.

Finally, the camera is pointing through an aperture in the +Z side of the spacecraft. The 2m whip antenna of the spacecraft will also be oriented along the +Z axis. It is expected that the 2m antenna will appear in the images once the antenna is deployed. Therefore, the images will be useful early on in the life of the spacecraft as a verification of the antenna deployment mechanism.

3 Space Environment Concerns

One of the most difficult aspects of this project was the proper selection of components for operation the environment of Space. This brings up concerns over temperature of operation, radiation, and operation in vacuum. All components were selected based on their ability to operate in the environment of Space.

3.1 Thermal

Dick Jansson provided a thermal study of the Fox-1 spacecraft that was published in the proceedings of the 2012 AMSAT Space Symposium. According to this document, if a full sun orbit is achieved, the camera cards will have a temperature of approximately $+5^{\circ}\text{C}$. If a 33% orbit is achieved temperatures for the camera cards are expected to fluctuate around -10°C with a minimum temperature around -15°C . For each component, when possible, the industrial version was selected that provides for operation down to temperatures below 0°C . The exception to this is the AL422B FIFO, whose minimum temperature of operation is exactly 0°C according to the datasheet. Unfortunately, there is no suitable replacement for this component. Additionally, the OV7670 camera chip datasheet specifies a minimum operating temperature of -30°C , but 0°C for a *stable image*.

On the positive side however, the thermal specifications for these components assume operation in an environment with atmosphere. When in vacuum these components will not be able to dissipate heat through convection, thus it is believed that they will be capable of operation a bit below the 0°C . Further testing will be conducted to determine the actual minimum temperature. This issue with the lower thermal limits of the components may also need to drive operational decisions about the appropriate times to activate the camera on the spacecraft. A table summarizing the component datasheet temperature ratings is given below.

Table 2: Component Temperature Range Summary from Datasheets

Component	Storage Temp	Operating Temp	Note
OV7670	-40°C to $+95^{\circ}\text{C}$	-30°C to $+70^{\circ}\text{C}$	operational
OV7670	-40°C to $+95^{\circ}\text{C}$	0°C to $+50^{\circ}\text{C}$	stable image
NAND	-65°C to $+150^{\circ}\text{C}$	-40°C to $+85^{\circ}\text{C}$	“free-air operating”
AL422B FIFO	-55°C to $+125^{\circ}\text{C}$	0°C to $+70^{\circ}\text{C}$	
MCU	-65°C to $+150^{\circ}\text{C}$	-40°C to $+85^{\circ}\text{C}$	
MRAM	-55°C to $+150^{\circ}\text{C}$	-45°C to $+95^{\circ}\text{C}$	industrial version
Vregs	-65°C to $+150^{\circ}\text{C}$	-40°C to $+150^{\circ}\text{C}$	

3.2 Radiation

For the desired orbit of the Fox-1 spacecraft, it is known that the spacecraft will be exposed to radiation. The spacecraft will regularly pass through the South Atlantic Anomaly where the Van Allen Radiation belts dip down. Due to this concern, certain steps have been taken to ensure the camera will continue to operate properly.

First, the actual selection of a CMOS camera sensor over other technologies, such as charge coupled devices (CCDs), was a direct result of the radiation concerns. Additionally,

CMOS components have lower power requirements increasing the attractiveness of CMOS technology for cubesat operations where Size Weight and Power (SWaP) are critical concerns. Second, in the power section of the circuit, load switches are utilized. These load switches have an automatic reset feature that should allow for protection against latch-up events should they be caused by single event anomalies. At this time the individual components have not been tested concerning long term doses of radiation, and therefore it is currently unknown how long the camera board will last in the prolonged presence of radiation.

Finally, with the exception of the FIFO's DRAM, both the MCU and the external MRAM memory have characteristics that should allow for proper operation in a high radiation environment. For example, the use of Error Correction Coding will be implemented during memory write/reads to/from the external MRAM. At no time will an image be stored for a long duration on the camera board, thus there is only a small window of time during the image acquisition/compression/download periods where a single event anomaly could cause memory corruption and thus failed image downloads.

3.3 Vacuum

Since the camera board will be operating in Low Earth Orbit it will be in a vacuum. There are two key aspects of operation in a vacuum that have been taken into account for this project, outgassing and thermal effects. Most lenses with small form factor are constructed with plastic for lightweight use in phones, but using a plastic lens in a vacuum would result in significant outgassing that could cause the lens to be obstructed. This could lead to a distorted image or worse, a black image from outgassing debris over the sensor. An extensive search was conducted until the team finally was able to locate a glass lens mounted in a black anodized aluminum housing to fit the form factor requirements from Marshall Electronics (PN V-41061D). Unfortunately the lens mount is constructed from plastic, thus necessitating the fabrication of a custom lens mount out of aluminum. The lens mount is then anodized black as well to help prevent light leakage and to protect against corrosion from the space environment.

The mounting of the camera lens brings up concerns about vibration. In order to secure the lens during launch as to not lose focus during the flight, space rated glue is needed with minimal outgassing properties as it will be right next to the camera sensor. The glue chosen is NuSil CV-2946. The glue will be put on the lens threads where it connects to the mount and on the lens set screws that will provide an additional physical securement of the lens. In addition to those, the screws that connect the lens mount to the board will also be secured with the glue. All five of these threaded locations will be secured with this glue.

Additionally, due to the stringent requirements for soldering for space applications, the actual population of the flight boards will not be done at Virginia Tech. Instead, a company was located that is willing to work with our team at a reasonable price for our low volume needs for population of the final flight boards. This company is Fast SMT (www.fastsmc.com)

and is capable of NASA Certified board population. The primary concern here is the use of lead based solder (necessary to prevent the “whiskering effect” and taboo in a University lab environment) and the use of low outgassing rosin. Finally, once the flight boards are populated, a conformal coating will be applied to further protect against the “whiskering effect” (excluding the camera sensor itself of course).

As mentioned in Section 3.1, the operation of the camera board in a vacuum is actually a positive from a thermal point of view. The inability to conduct heat away from convection will allow the components to retain heat for a longer period, hopefully dropping the lower limit of operation in terms of temperature. Additionally the datasheet specifications assume operation in a environment with atmosphere, and thus are likely a bit high relative to when the components are operated in a vacuum.

4 Software Development Overview

This experiment card uses an ST Micro STM32L151ZDT6 Low-Power ARM Processor to perform all required tasks. The STM32L1 allows for 32-bit processing and DMA peripherals with a 48Kb SRAM for processing the JPEG data. Table 3 shows the basic specifications of the processor.

Table 3: STM32L1 Specifications

Property	Specification
Speed	32 MHz
Rated Current	238 μ A/MHz
Program Flash	382KB ECC
Memory	48KB ECC SRAM
EEPROM	12KB ECC EEPROM
Footprint	LQFP144

As described in the hardware description, the processor has several hardware peripherals attached to it other than the satellite IHU: 8Mb SPI MRAM, 3Mb dual-port DRAM FIFO, and the OV7670 camera sensor. These interfaces and connections are described in Table 4

Table 4: Peripheral Specifications

Peripheral	Bus Type	μ C Interface	Speed
MRAM	SPI	DMA Hardware SPI	32MHz
FIFO	8-bit Wide Clocked	Software Bit-Bang	3.2MHz
OV7670	I2C-like Two-Wire	Software Bit-Bang	25kHz
IHU	UART	DMA Hardware UART	38.4kbaud

A real-time operating system (RTOS) is used for task management and hardware abstraction. The software team chose ChibiOS (<http://www.chibios.org/>), a GPLv3 RTOS, for use on this stem. The HAL and other device management features of the operating system were intuitive to learn. However, in prototyping and development there were some adaptation problems with the ChibiOS version used. After migrating from STM32L1-DISCOVERY boards to actual design prototypes it was discovered that ChibiOS did not fully implement the High-Density STM32L1 devices. The OS source had to be modified to expand the PAL and HAL to accommodate the expanded device capabilities.

Programming and development of this system was done entirely on linux-based systems. An ARM cross-compiling toolchain was built for GCC; our specific toolchain is available at <http://wq3c.net/arm-cc.tar.bz2> . To flash the STM32L1-DISCOVERY and the design prototypes, the ST-Link (v2) interface was used. Similar to our discovery with ChibiOS, our selected flash utility (<https://www.github.com/texane/stlink>) did not fully support the high density devices. The stlink project was forked and modified with necessary modifications for programming our device (<https://www.github.com/mitchd/stlink>).

Table 5: ChibiOS Key Features

1.2-5.5 KiB Kernel Size
Preemptive scheduling, round-robin for like priorities
128 priority levels
Mutexes, semaphores, events, message queues
Thread-safe heap
Hardware abstraction layer with STM32L1 support
GPLv3

5 System Architecture

5.1 Threads and Tasks

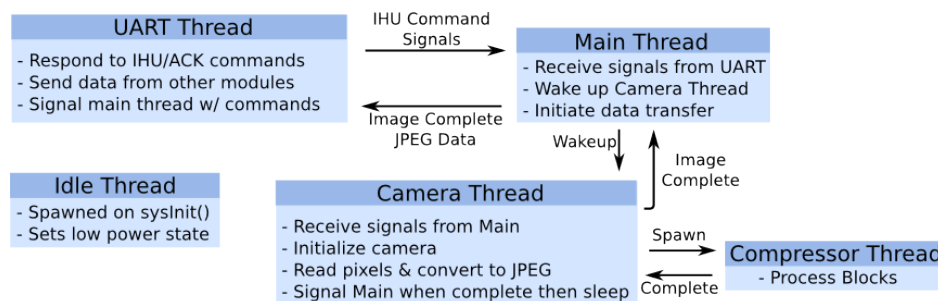


Figure 3: Task Diagram

Figure 3 describes the task diagram for the imaging experiment. Multiple threads are utilized to take advantage of different priority levels provided by the RTOS and increase code modularity. A flowchart in Figure 4 describes in greater detail the sequence of events for capturing and transmitting a picture. Not shown on the flowchart is a default command to take a picture. Due to systems operations and simplification, it is assumed that when the experiment is powered on, a picture is requested.

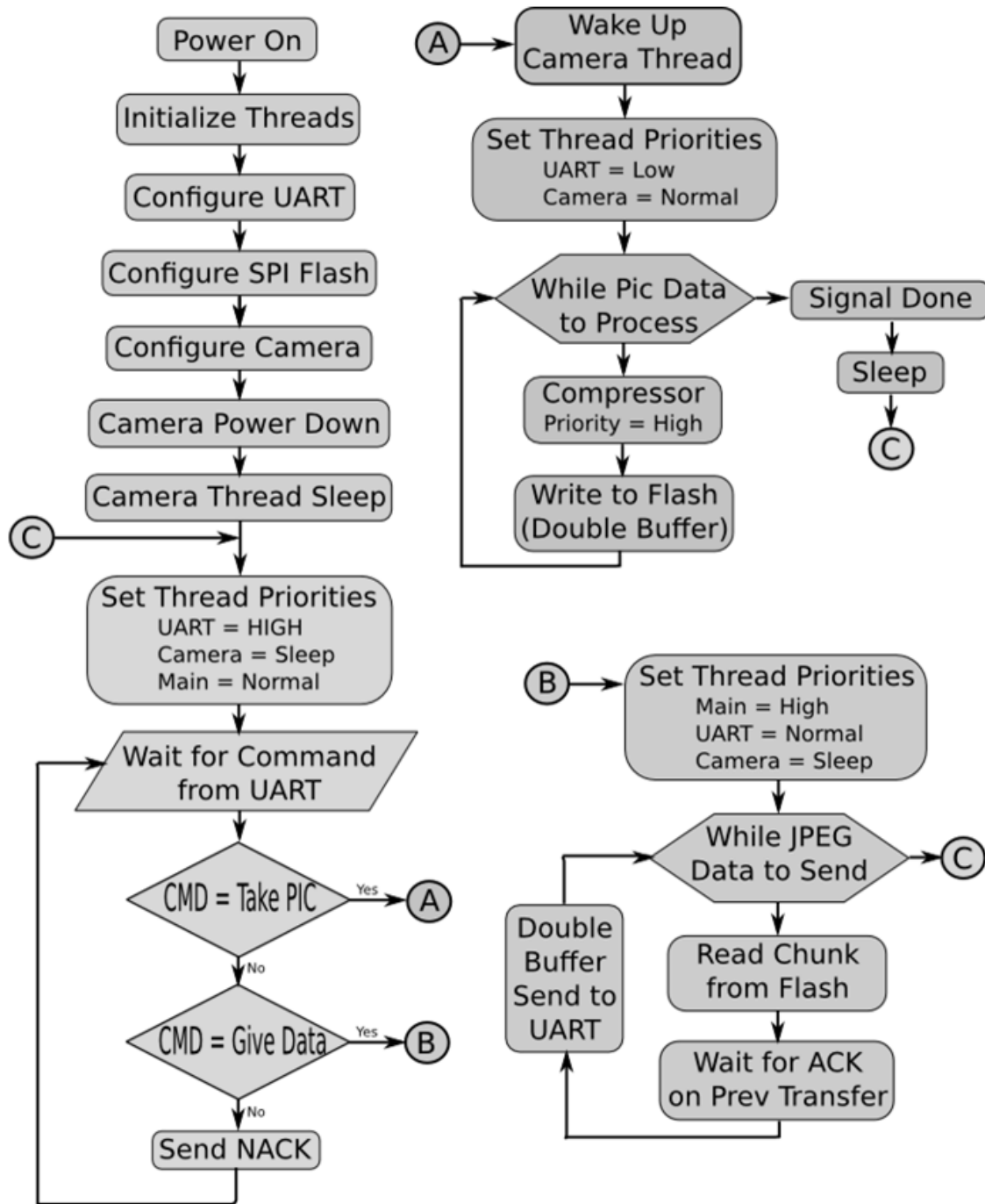


Figure 4: System Operation Flowchart

5.2 Image Processing

The OV7670 camera module provides 4:2:2 YUV data to the processor through the DRAM FIFO. Due to limitations in the FIFO storage space, the image is divided into two parts for processing. JPEG compression is achieved by reading eight horizontal lines from the FIFO and passing to the JPEG compressor. For the purpose of this description, these eight-line segments are called ‘scan lines.’ The JPEG algorithm processes images in eight by eight pixel chunks: performing a discrete cosine transform, quantizing the results, then huffman coding the quantized data. This particular implementation uses a library ‘jpegant’ (<https://code.google.com/p/jpegant/>) which implements an integer approximation of the DCT. It should be noted that the Google Code version of jpegant is GPLv2 (which is incompatible with GPLv3), the author was contacted and we were authorized a GPLv3 release of his code.

The JPEG compression routine makes use of a little-used feature in the JPEG specification: the RSI marker. RSI is the ‘restart interval’ of the huffman coding. This allows for missing data in the received image, while the image will not look complete it will not render the entire image useless. The target compression ratio for the 640x480 image is at least 15:1 compression; each scan line should be less than 1023 bytes.

5.3 Data Storage

Image data is stored on the 8MB MRAM module after processing. A predefined address in the MRAM module contains a data structure which contains important information about the image: a memory map of each scan line (beginning and end addresses) and a checksum. Should time warrant before final release, ECC will be implemented in the MRAM storage and retrieval routines.

6 Personnel

Though the authors of this paper (Graduate students in Electrical and Computer Engineering) have been the core developers of the hardware and software for this project, many people affiliated with Virginia Tech have contributed to this project, the majority of which hold Amateur Radio licenses. The personnel involved include undergraduate students, graduate students, post-doctoral researchers, VT employees, and alumni. Dr. Robert McGwier, N4HY, former VP of Engineering for AMSAT, is the project's principal investigator and is currently the Director of Research at Virginia Tech's Ted and Karyn Hume Center for National Security and Technology, the group that provided funding for this project.

Population of the prototype boards, to included the incredibly difficult soldering of Micro Ball Grid Array components, was accomplished by two undergraduate students, Alex Mosolgo and Kevin Lee. The mechanical design and fabrication of the lens mount was accomplished by a third undergraduate student, Danny Tyndall, K3WDT (also the President of the Virginia Tech Amateur Radio Association, K4KDJ). Mitch Davis, WQ3C, (EE Masters Student, Hume Center) and Kevin Burns, KJ4SYL, (CE Masters Student) are the key developers of the software for this project. Dr. Joseph Gaeddert, KK4MNZ, was a post-doctoral researcher with the Hume Center that assisted in the software development. Matthew Via, KK4EAB, is a Virginia Tech Alumni with a B.S. in Computer Engineering and also assisted in the software development. Bill Clark, KK4EWQ (E.E. Direct PhD Student) and Zach Leffke, KJ4QLP (E.E. Masters Student) are both graduate students with the Hume Center and were responsible for the hardware aspects of the project to include the development of the schematic and layout, environmental concerns (radiation, thermal, vacuum, etc.), and interfacing with external subcontractors. Sonya Rowe, KK4NLO and Michael Fowler, KG4MAX are employees of the Hume Center that provided program management services as well guidance during the Preliminary Design Review and Critical Design Review sessions. Dr. Dennis Sweeney, WA4LPR, is the director of Instructional Labs at Virginia Tech and provided equipment for the fabrication and population of the prototype boards through the VT ECE Integrated Design Studio as well as invaluable guidance in the development of electronics destined for operation in Space. All names and call signs (where appropriate) of the personnel involved in this project are included on the silkscreen of the Experiment 4 Card.

7 Schematic and Layout

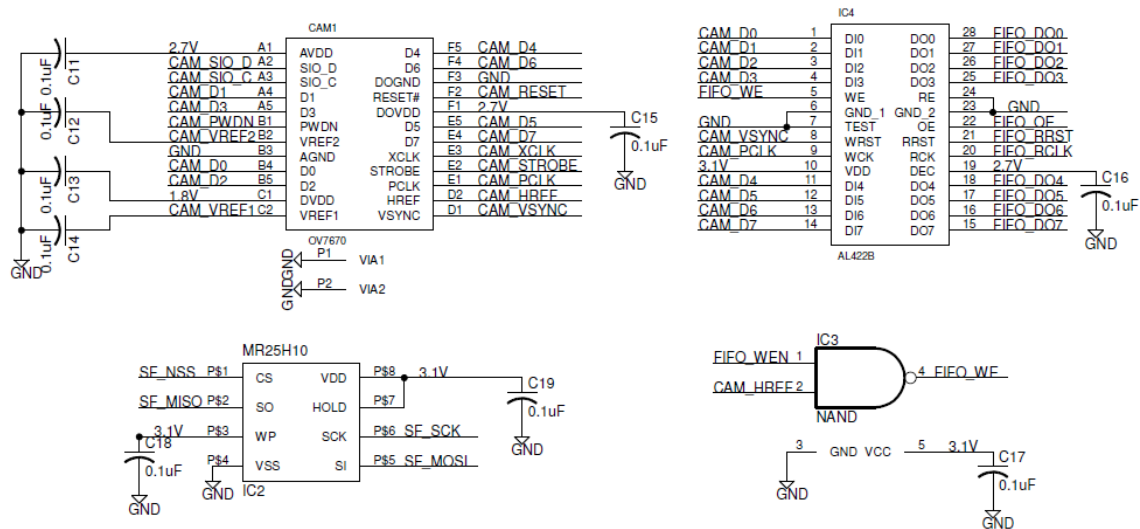


Figure 5: Experiment 3 Schematic - Peripheral Components

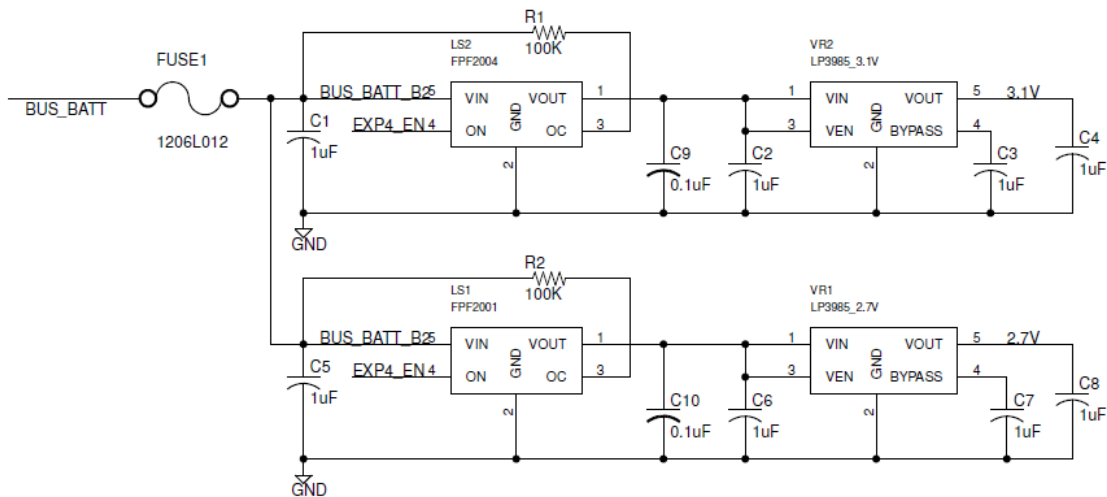


Figure 6: Experiment 3 Schematic - Power

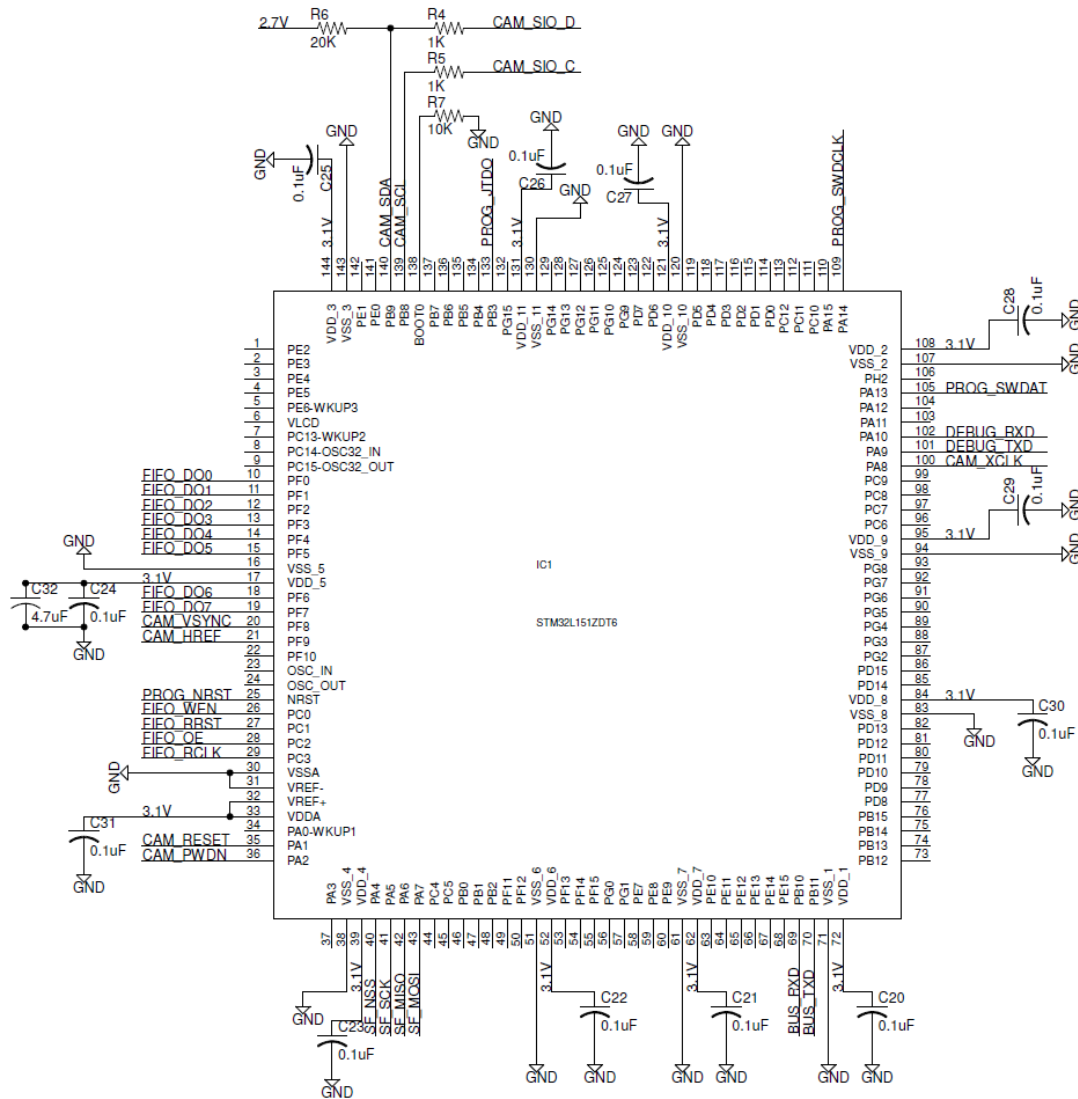


Figure 7: Experiment 3 Schematic - Microcontroller

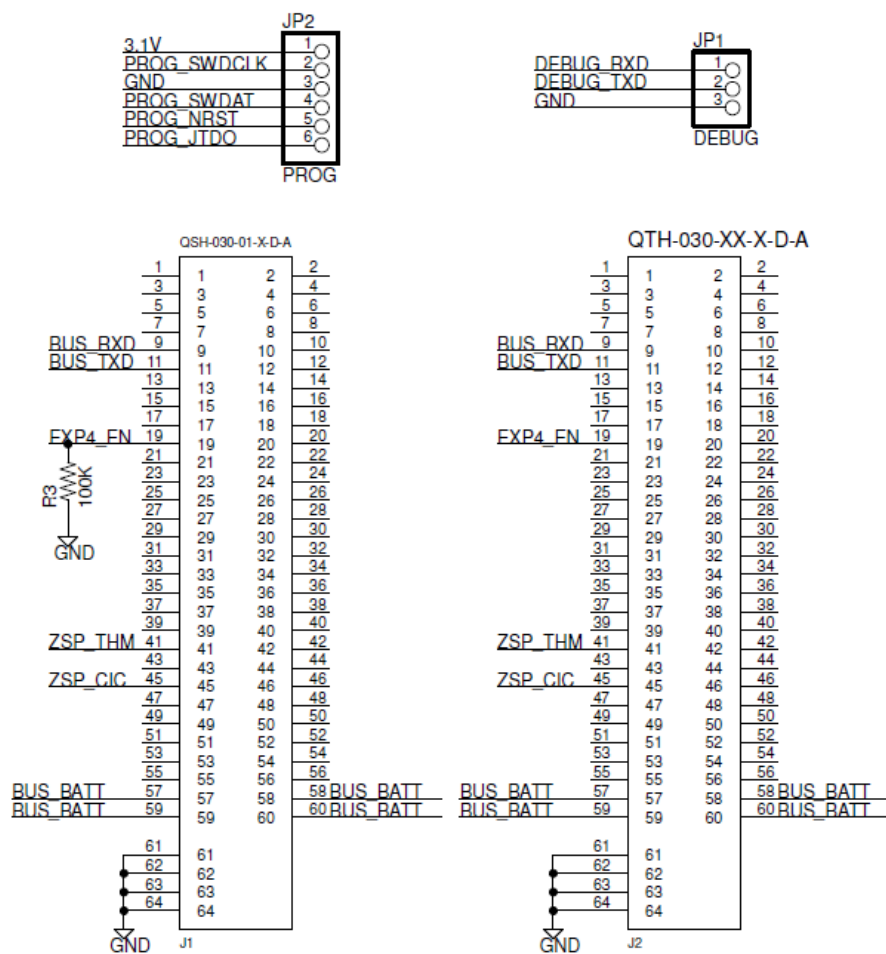


Figure 8: Experiment 3 Schematic - External Connectors

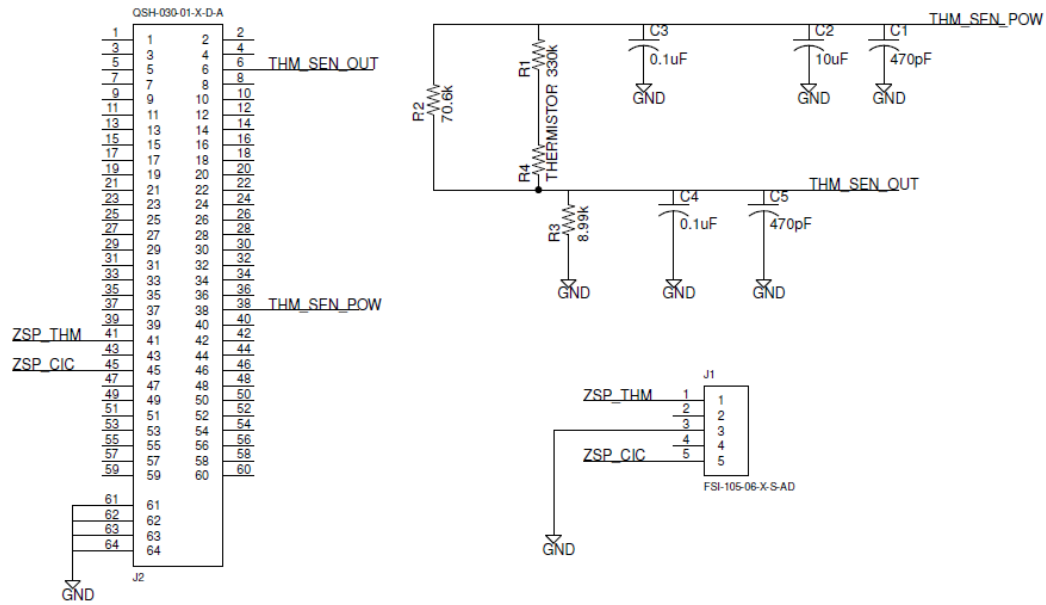
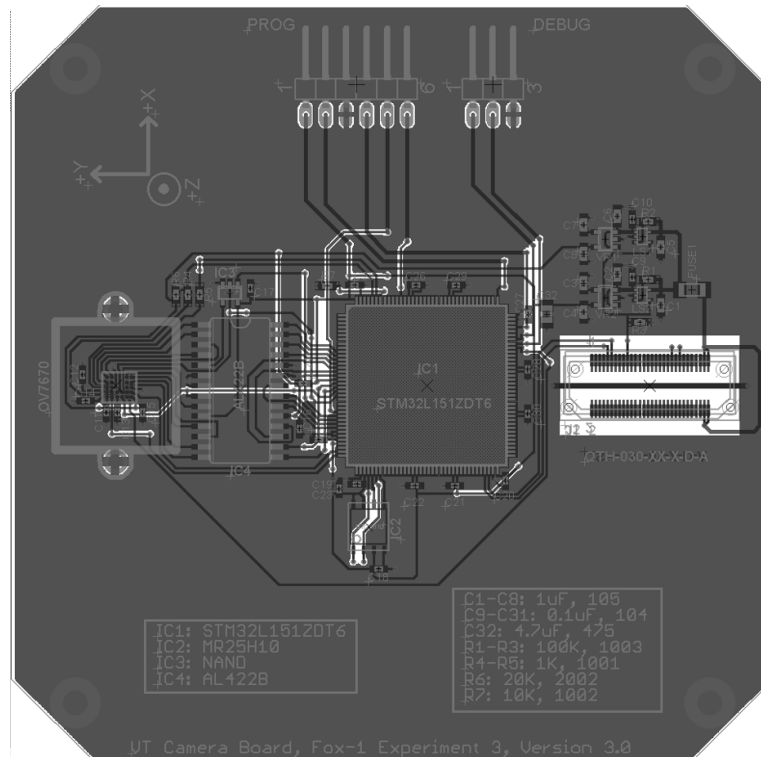
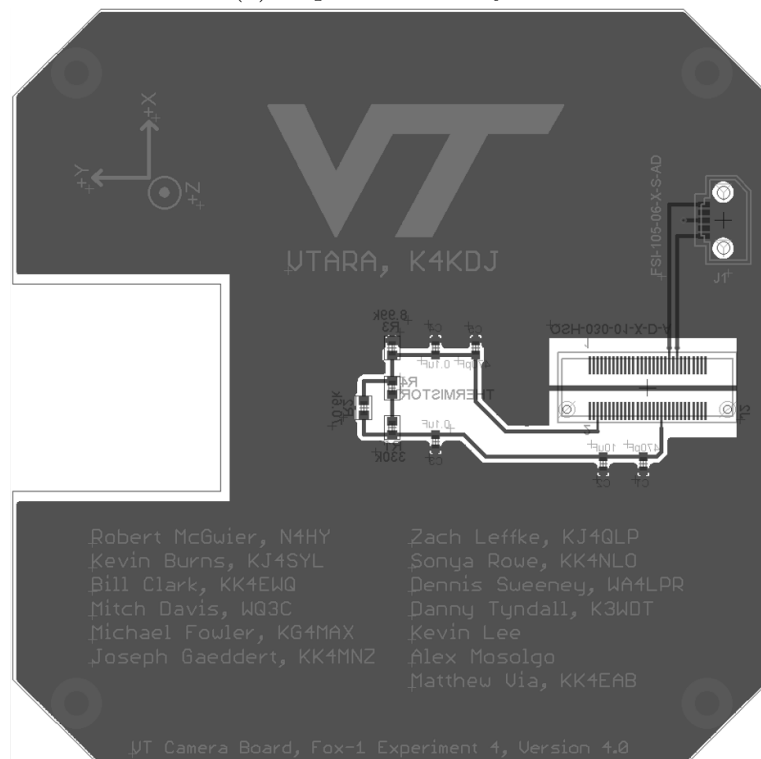


Figure 9: Experiment 4 Schematic



(a) Experiment 3 Layout



(b) Experiment 4 Layout

Figure 10: Camera Board Layout

AMSAT Education and You!



**E. Michael McCardel, KC8YLD, kc8yld@amsat.org
V.P. for Educational Relations**

2013 AMSAT Symposium, Houston Texas, November 1-3, 2013

Acknowledgements

I would like to thank Mark Hammond, N8MH, for his service as V.P. for Educational Relations here at AMSAT. His leadership and vision have brought us a good distance over the past two years. He has laid a foundation upon which we can build as we go forward. I am very happy that he will continue working with AMSAT as a member of Board of Directors

I also want to thank the AMSAT Education Team, Associate Directors, Joe Spier K6WAO and Dale Hunzeker KJ6VUC who have worked tirelessly behind the scenes to build relationships and guide projects. Lastly, I need to recognize Mark Spencer, WA8SME, our partner from ARRL's Education and Technology Program. Much of the educational tools he has developed are directly applicable to the AMSAT goals as they relate to K-16 educational resources. He has a clear vision of how to apply STEM standards in our schools.

Why is education important to AMSAT?

Well, it is a part of our mission and our vision.

Our Mission Statement includes,

“AMSAT is a non-profit volunteer organization which designs, builds and operates experimental satellites and promotes space education. We work in partnership with government, industry, educational institutions and fellow amateur radio societies. We encourage technical and scientific innovation, and promote the training and development of skilled satellite and ground system designers and operators.”

Our vision states

“Our Vision is to deploy satellite systems with the goal of providing wide area and continuous coverage. AMSAT will continue active participation in human space missions and support a stream of LEO satellites developed in cooperation with the educational community and other amateur satellite groups.”

In fact when [The](#) Radio Amateur Satellite Corporation (as AMSAT is officially known) was first formed in the District of Columbia in 1969 it was founded as an educational organization.

More recently we have become quite aware that Education has quickly become critical for our ride to space. Much of what we do has many Educational tie-ins from K-16. In K-12 STEM education has become the standard and meeting these standards is a critical aspect that teachers are struggling to accomplish. AMSAT has the experience and expertise to assist teachers with obtaining their goals of incorporating STEM standards into their pedagogy. This is especially true when we combine resources and knowledge with our partners at NASA and the ARRL. More Universities are developing CubeSat missions. We can help them with their missions by supplying them with a vehicle that has sound avionics that allow them to easily plug in their experiments. AMSAT already has Academic Partnerships with Penn State (mems gyro, on Fox-1), R.I.T. (MPPT on Fox-1a & b), Virginia Tech (special payload on Fox-1a), and Vanderbilt (Radiation science on Fox-1a & b).

We missed a great opportunity with ARISSat-1 by not being prepared in time to push an educational agenda that we could supply schools in assistance to their STEM activities.

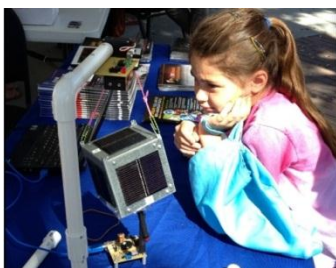
With Fox-1, Fox-2, and perhaps ARISSat-2 and 3, we have an opportunity to develop educational tools experiences that we ran out of time with ARISSat-1.

An educational initiative can serve us well in membership recruitment and fund raising. As we become engaged and excited with our educational partners we not only educate them and the public but we educate ourselves and we become better promoters for our product. As others outside AMSAT see the positive impact we are having on education they will be more will to assist and contribute to our efforts.

SUCCESES

In our educational outreach of the past couple of years we have had several successes. At Pacificon in October of last year we were to put on displays of how amateur radio satellites related STEM requirements. The ARISS contact at the stage of ARRL's National Convention, which was ably coordinated by Joe Spier, W6WAO, not only brought us attention and some good PR but also brought an experience into the hands of the youth at the convention that served as an incentive to follow a course of study in STEM related courses and perhaps towards STEM careers. Coupled with the contact Dale Hunzeker KJ6VUC used the CubeSat Simulator developed by Mark Spencer, WA8SME to demonstrate working with live data and I assisted volunteers in the Youth Lobby with the building of paper Fox models demonstrating meeting STEM skills of measuring and direction following to younger students. At the same time Tom Deeble, KA6SIP was demonstrating making live portable satellite QSO's using the ARRL Callsign W1AW/W6

In March of 2013 Dale, in cooperation of the Pasadena Radio Club, engaged the youth of Monrovia California at their Science Expo. Included in this AMSAT presence was a live ISS video downlink, CubeSat simulator demonstrations and Amateur Satellite Communication Demonstrations.



Monrovia Science Expo

In June Richard Siff W4BUE of the Amateur Memorial Radio Club in Chesapeake, VA contacted Mark Hammond and the educational team with a request for ideas and help with a presentation to 225 Chesapeake Public Schools science teachers. Dale coordinated with their request and had me send them one of our CubeSat simulators. This specifically met their request for hands on learning material. The Chesapeake group made good use their tools, as reported and a recent ANS, the Chesapeake group used the simulators and other resources to present to

- * STEM Technology teachers Chesapeake Schools 200 + (K5VIP)
- * Western Tidewater Amateur Radio Club 30 (W4VX)
- * Society of Broadcast Engineers Chapter 54 at the WHRO Studios 30 (W4BUE)
- * Virginia Beach Amateur Radio Club 30 (KN4KL)
- * Virginia Beach Hamfest Forum and table 75 (W4VX / W4BUE)
- * Chesapeake Center for Science and Technology High School VO TECH, WFOS / W4FOS. 8 students

They are currently in "standby" for STEM teachers to discuss lesson plan(s).

Presentations included the following information: (1 hour)

- * CubeSat
- * Video of edited clips from Dayton Youth Forum and our VO Tech about 20 mins. Clips: - SAT COM - Robots - DX - High Altitude Balloon MIT Letter Hack - School Club Roundup
- * STEM presentation



K4AMG Amateur Memorial Radio Club

So what's next?

We have several challenges which I believe we can meet. We have almost a year to put forth an educational outreach to succeed in meeting many of our educational objectives, before Fox-1 launches. We need to develop tools, opportunities and activities that meet STEM requirements. We need to engage educators and offer our assistance in writing lesson plans and developing activities directly related to Fox and it's on board scientific experiments. We need to get word out to schools in reference to the educational opportunities available through the satellite.

We believe much of the work Mark Spencer has already put forth in his development of several simulators has given us a head start. Mark has developed

Tracking simulator

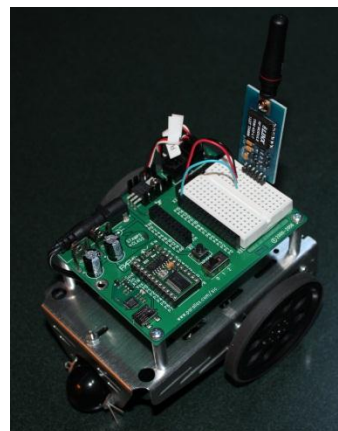
CubeSat simulator

MAREA- the Mars-lander ARISS Robotics Exploration Activity

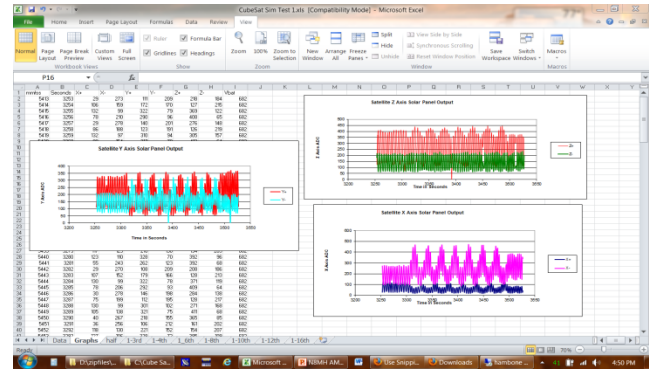
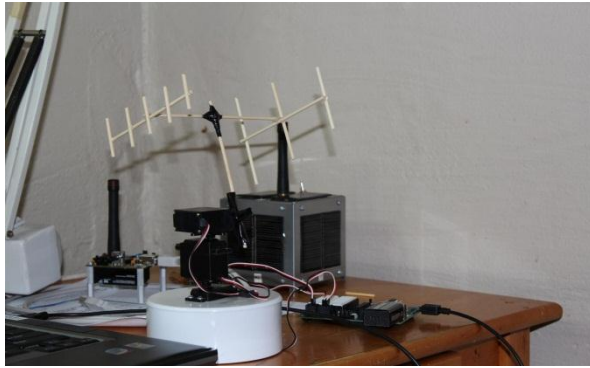
Yaesu FT-817 Sat CAT controller

WRAPS, Wobbler, RadFx, Antenna Pointing System

AMSAT already has and have deployed the tracking simulators and CubeSat simulators. I hope we can construct and have available MAREAs, and WRAPS, and perhaps other innovations for loaning as well.



MAREA, the Mars-lander ARISS Robotics Exploration Activity



CubeSat and Tracker Simulators

We also have an opportunity to learn from FUNcube and the UK educational initiative when it launches next month.

We have an opportunity with the ARRL Centennial Celebration in Hartford Connecticut next July. We have already begun planning to participate in ARRL sponsored learning sessions to be held on Thursday. AMSAT will hold a forum on during the celebration and we are working ward establishing an ARISS contact during the convention.

Communicating Our Successes

We need to better communicate our activities. Many individuals and clubs do demos at hamfests and club meetings and schools that go entirely unreported or documented. We need to be better self-promoters. Let us know, in advance if possible, what activities you plan to support. We'll help promote them. And please report your efforts. ANS is our weekly news publication. The editors are always looking for submissions. Write an article for the Journal about your experiences. See JoAnne's call for articles and guidelines published in ANS 279 and on the AMSAT-BB. Send Pictures and charts. We can use this information in the Journal and on our website as well. We will all benefit from your effort.

There is another resource we need to promote and populate. That is the AMSAT-EDU bulletin board. As the moderator for the AMSAT-EDU BB, I acknowledge we do not have many posts. What I would like to see it become is a place and resource for educators and AMSAT members to interface, collaborate, share ideas, offer support and generate materials to meet our **and their** educational objectives. To make this happen we have to

reach out to educators and get them to join the list. To subscribe to a mailing list from AMSAT.ORG, start on the ListInfo web page,

<http://www.amsat.org/mailman/listinfo>

and select (click on) the mailing list of interest, in this case AMSAT-Edu. This will bring up a simple form where you can enter your email address and subscribe by clicking the Subscribe button. If you wish to receive the messages bundled up into a daily digest, just select that option before clicking Subscribe.

Getting Started

How can we best get started accomplishing all of this? Let's start close to home. We start by better communicating among ourselves, especially the different departments within AMSAT. The more we know about what's going on the better we promote our efforts. The better we promote our efforts the more attention is drawn to our initiatives.

Get to know your area coordinator. (S)he is a great resource and can help your efforts when you are preparing a demo, program or display at hamfests, conventions, club presentations and school programs. Your Area Coordinator can help with contacts, suggestions and materials. Educational Relations is committed to work with the Area Coordinators and others by providing them resources as we have them available.



Materials Useful for hamfests, classrooms, etc.

Building Relationships with Schools

How do we get our message into schools? It is simple. Reach out to your children and grandchildren. Review their textbooks. Engage their teachers. Volunteer to do a demonstration. If we work together it will all come together.

As I mentioned earlier let's pay attention and learn from the UK's effort with FUNcube, which launches in November. FUNcube's purpose is to integrate with the UK's curriculum by focusing on STEM education, especially in the area of radio, electronics, physics and orbital mechanics. Their lesson plans will be easily adapted for our use as well. You will be learning about FUNcube at the Symposium.

HELP WANTED

We are a volunteer organization and we need your help. Things only get done if we do them ourselves.

We need

- Web content person(s) for AMSAT's education outreach web pages
 - Maintain calendar of amateur radio youth events
 - Assist in populating the AMSAT Education Outreach web pages with useful information
- Archivist/publicist of satellite educational activities (photos, stories for Journal, press, videos)
- Web researcher to "mine," collect, and organize existing lesson plans/ideas that may prove useful
- K-12 educators that can write lesson plans/ideas using satellite telemetry, etc. related to science, technology, engineering, and math (STEM).
 - ARISS, Fox Satellites related lesson plans
- Mentors and ground station operators (with equipment!) for ARISS contacts
- Assemblers to construct simulators for distribution

What can **YOU** do to help?

- Join AMSAT and if you are a member to actively recruit new members
- Join the AMSAT-EDU mailing list (www.amsat.org for details/instructions)

- Engage educators to join AMSAT-EDU
- Volunteer for a specific task! kc8yld@amsat.org
- Educators: We need lesson plans/ideas related to satellites and amateur radio
- Educators: sign up for ARRL Teacher's Institute program!
 - Or if you know an Educator, encourage them to sign up for ARRL Teacher's Institute program!

Contact me kc8yld@amsat.org



Using amateur radio satellites in education: an exciting topic to attract students to science and engineering

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Abstract

In sciences and technology, experimental and interdisciplinary activities are fundamental to stimulate the interest and motivation of students. This project also aims to strengthen the link between school/university, proposing the creation of a portable didactic laboratory for space communications using amateur radio satellites, where the main objective is the introduction of devices and concepts in the daily lives of students, such as communication satellites, antennas, digital coding techniques, among others. In addition to motivated to continue a career in engineering, this project aims to strengthen the experimental teaching in the disciplines of the course Electrical and Electronic Engineering at the university level. This will be possible through the application of theoretical concepts taught mainly in the disciplines of Telecommunication emphasis on experiential activities that will be offered by this project.

Introduction

Brazil has invested and intends to continue investing increasingly in aerospace. It is planned for the next years launch of the first national communications satellite. This space station will be dedicated primarily to the national Internet broadband project (PNBL). Currently, aerospace (and its ramifications more direct), it shows a major lack of skilled labor from all other areas of sciences and technology in Brazil. History has shown that countries with a high degree of development, economic growth and sustainable development is based on an education that develops skills, competencies and attitudes necessary for life and work, hence the importance of education for citizenship and linked to technological development.

Objectives

The main objective of this project was to build a small and low-cost didactic laboratory for space communications for use in the course of Electrical and Electronic Engineering from the University of Vale do Rio dos Sinos (UNISINOS) and in the electronic technician course at the School Liberato Salzano Vieira da Cunha (Figure 1). The Electrical and Electronic Engineering course at UNISINOS have about 1500 undergraduates students.



Figure 1. The University of Vale do Rio dos Sinos, UNISINOS. São Leopoldo, RS. Brazil.

This project also aims to be a motivator for high school students pursue a career linked to engineering, especially electrical and electronics. Similarly, aims to reduce dropout in these courses. For students of higher education, this project can encourage the training of professionals who will follow after the completion of their courses a specialization in aerospace or related fields.

Picosats in curriculum

Several experimental activities using the portable laboratory have been added to the electronic technician classes and advanced courses in electrical engineering at UNISINOS. The aim of these courses is to prepare the students for their future professional careers in RF and Microwave Engineering and for the sequence of senior courses, such as Antennas and Propagation, Microwave Theory and RF Microelectronics. Some of these courses are offered as technical elective courses in the curriculum of the EE program of the university. The courses are structured with a balance between theory and laboratory measurement and evaluation, modeling. During the course the students are asked to design, implement, and measure devices for the portable satellite amateur radio station, like RF filters, RF low noise amplifier and antennas as is show in Figure 2.



Figure 2. Antenna testing activities in the Department of Electrical and Electronic Engineering at the UNISINOS. This figure show a Dual band cheap-Yagi antenna.

Students have learned how to measure parameters of antennas and filter using VNA. Additionally, after learning how to use the Antenna and Microwave CAD program like HFSS (HFSS, 2013), NEC2 (NEC2, 2013) and MMANA(MMANA-GAL, 2013), the students are ready to design an RF filters by using the substrate and design requirements given by the course instructor. Accordingly, this part of the course is designed to help students to practice what they have learned in the theory, CAD and laboratory activities. The success (or not!) of the designed products is also discussed by the students.

Hands-on activities

The principal activities have focus on space communication (antennas, propagations, notions of theory about the devices used in aerospace, modulation systems, simulation of orbits, etc.) using amateur radio LEO satellites (VO-52, FO-29, SO-50, LO-19, etc). These activities are carried out alternately with laboratory activities, actions focused on the use of more specific technical, and other embedded in the local community, through theoretical and practical workshops, which basically employ very simple equipments (Steve, 2013). The Figure 3 show the portable station. In the portable operation we use a dual band (2m/70cm) cheap-Yagi (Crow R. F. 2006). The antenna is mounted to a lightweight photo tripod. This arrangement allow easy azimuth, elevation, and polarization control during the pass. The Figure 4 presents a typical field day style classroom.

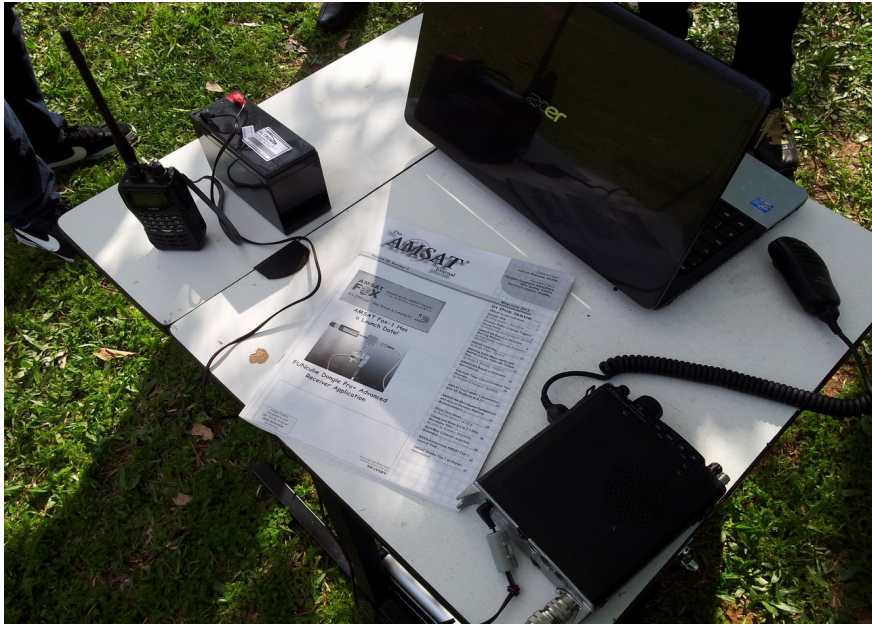


Figure 3. The portable station: a FT-817, HT Alinco DJ-G7, small dual band yagi; 12V/7Ah battery, laptop and AMSAT Journal!

The students are encouraged to conduct the experiments, analysis and interpretation. Emphasis also is try to build many parts of the setup, like antennas, low noise amplifier, etc. A didactic laboratory should spark interest and curiosity!



Figure 4. A typical field-day classroom.

Conclusion

This paper demonstrated that a low cost didactic laboratory for space communication using amateur radio satellites system could be used in engineering and sciences courses. Topics about antennas, RF filters, propagations, notions of theory about the devices used in aerospace, modulation systems, simulation of orbits, etc can be covered using low-cost equipments.

References

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NEC2, www.nec2.org (2013, September)

MMANA-GAL, hamsoft.ca/pages/mmana-gal.php (2013, September)

Richard F. Crow, Build This Cheap and Easy Satellite Uplink Antenna, AMSAT Journal, sep/oct, 2006.

Ford Steve, The ARRL Satellite Handbook, American Radio Relay League (ARRL), first edition. 2008.

Acknowledged

We acknowledge support from the Brazilian Institution CNPq.

Beyond The Grid Square

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Fox# Experiments

Mark Spencer, WA8SME
ARRL Education and Technology Program

My Purpose Today

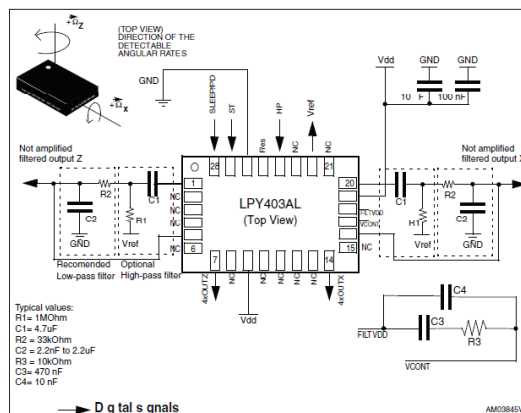
- To make the opportunities afforded by the Fox satellites accessible to schools outside the immediate University of interest, and to the general ham population
- Outline:
 1. Attitude Determination Experiment (Wobbler)
 2. Maximum Power Point Tracking (MPPT)
 3. WRAPS portable antenna rotor system to access Fox and other satellites

Attitude Determination Experiment (Wobbler)

“In addition to the communications package, Fox-1 will host an experiment payload. AMSAT is sponsoring a capstone project at Penn State University for the 2011-2012 academic year... The project will involve designing and constructing an attitude experiment based on a 3-axis, micro-electro-mechanical gyroscope. The experiment data will measure the performance of the satellite’s magnetic stabilization system...”

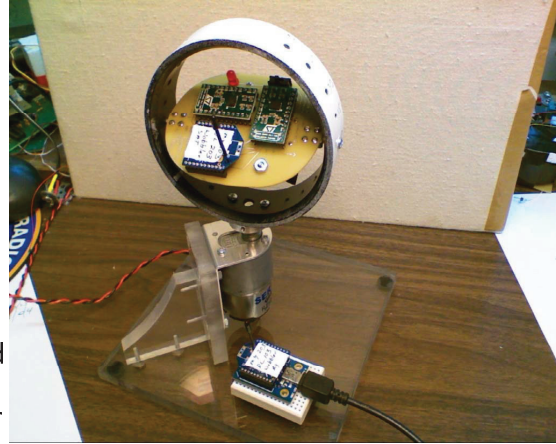
Attitude Determination Experiment (Wobbler Experiment)

- Use gyroscopes to directly monitor satellite rotation around the X, Y, and Z axes
 - Precedence has been to infer rotation rate from solar panel voltage/currents
- Gyroscopes contain an oscillating driving mass
 - Oscillation proportional to direction and rate of rotation
 - Oscillation converted to voltage

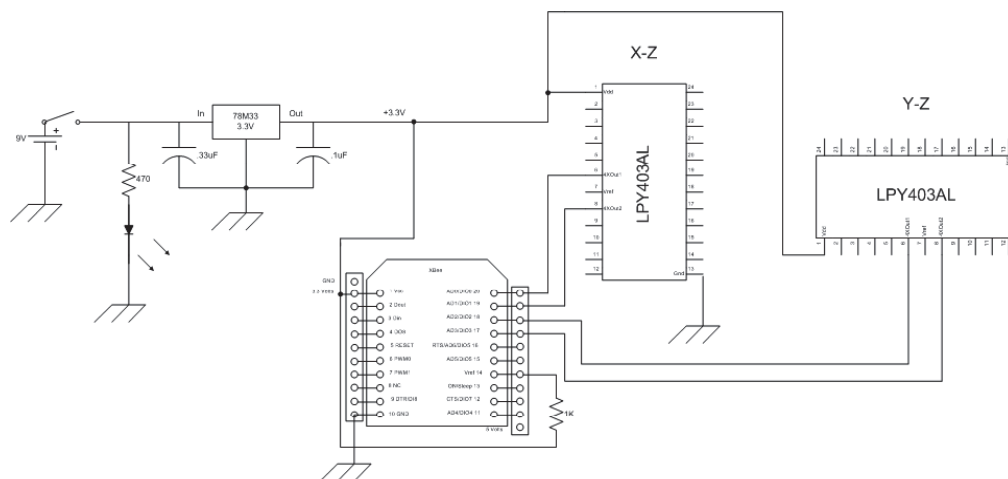


Wobbler In-classroom Simulator

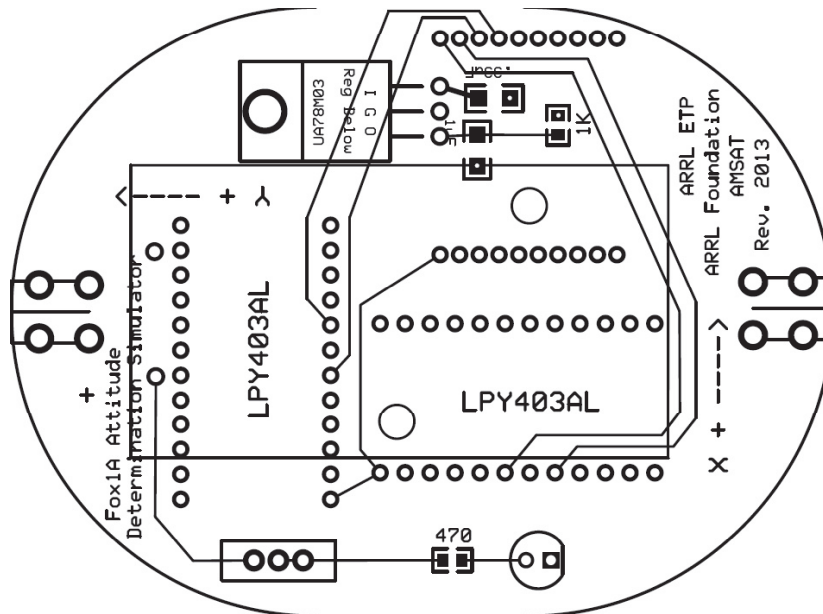
- Simulator uses actual gyroscope devices to be flown
- Mounted on rotator to simulate on-orbit behavior
- Data linked off-platform like the actual satellite
 - Manipulate the Wobbler board and see what data results
 - Capture real satellite data and see the Wobbler board gyrations that produce similar data



Wobbler Circuit



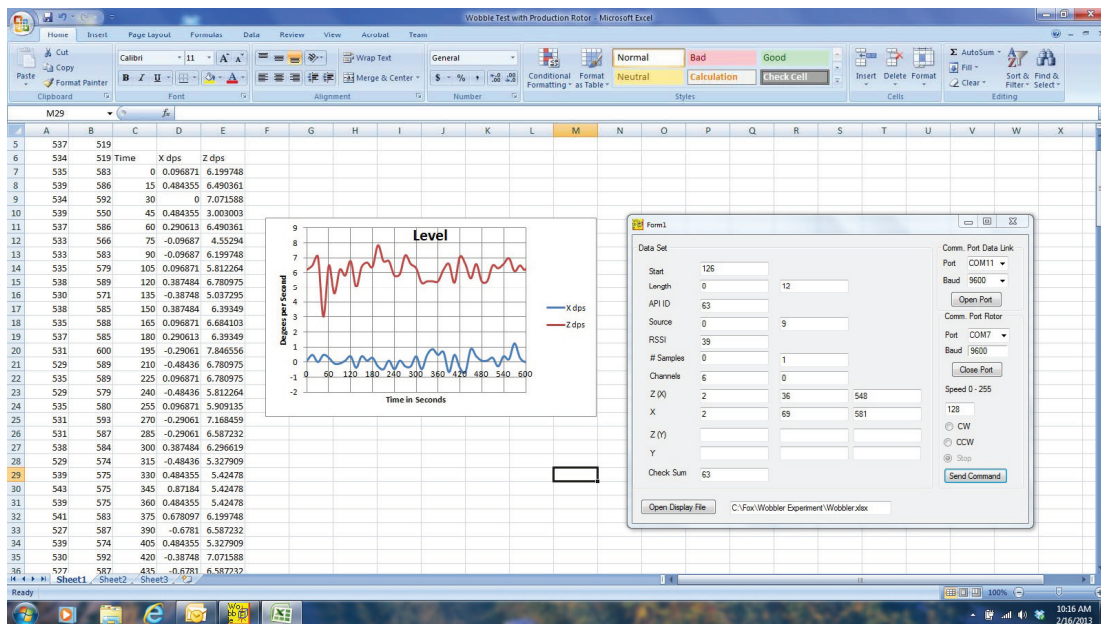
Wobbler PCB



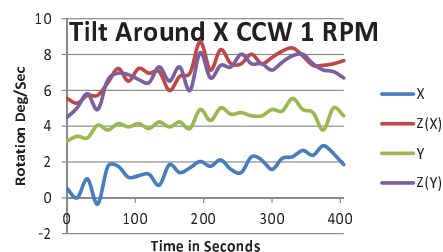
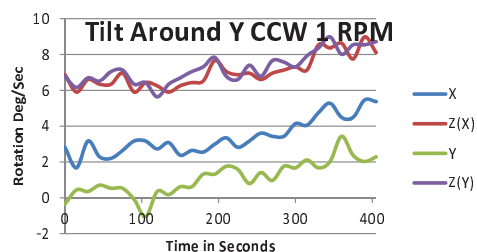
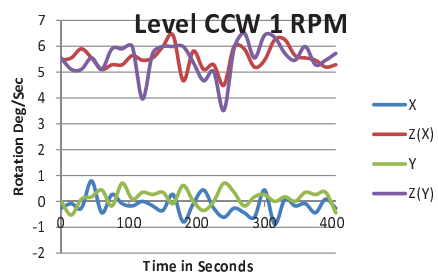
Wobbler Ground Station GUI

- GUI displays data transmitted by Wobbler board
- GUI also used to control rotator behavior (direction and rate of rotation)
- GUI dumps data to Excel for exploitation and graphing

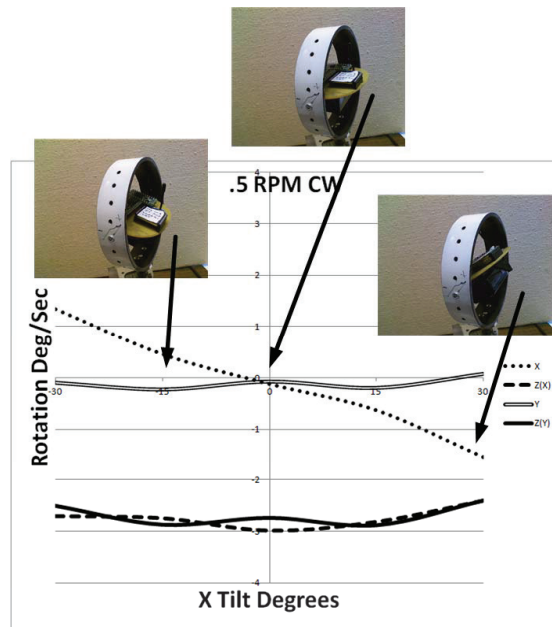
Wobbler Ground Station GUI



Data Analysis, the real value



Data Analysis, the real value



Exploring the Fox-2 Maximum Power Point Tracking System

By: Mark Spencer, WA8SME, ARRL Education and Technology Program Director

Rochester Institute of Technology (R.I.T.) engineering students have tackled the task of developing a maximum power point tracking (MPPT) system for use on the AMSAT Fox-2 satellite (see March/April 2013 AMSAT JOURNAL). Their task was to prototype a system that optimizes the power delivered by the satellite's solar panels. I have previously published an article on a project to make the Fox-1 Attitude Determination Experiment accessible through a classroom simulator. Likewise, in this article, I continue my quest to make these Fox satellite experiments accessible beyond the handful of college engineering students who are directly involved in the developing the experiment to those schools, teachers, students, and the ham satellite enthusiast (you, the life-long-learner) who want to learn about the experiments and the fundamental concepts involved. Here you will find a project (simulator) that will allow you to explore the concept of MPPT, see an MPPT system in action, and observe how it behaves.

The need to optimize solar panel performance is not unique to space borne systems. Today's green energy initiatives highlight the need to gain every watt of power available from solar and other alternative energy sources. So the study and understanding of the MPPT concept has broad appeal, therefore the project described here is not limited to the Fox satellites. Also it must be recognized that there are many different approaches to solving the MPPT challenge, and the approach described here is just one approach. In fact, the approach you will read about is for academic, learning purposes only, and is not a system that is anywhere close to "flight ready." The system is developed to present the fundamentals "bluntly and obviously."

Solar Panel Basics. To begin, a review of some solar panel basics are in order, and I stress basics. A solar panel contains layers of stratified material that is sensitive to light and a solar panel will therefore produce a current when exposed to light. The amount of current produced depends on a number of factors but we'll look at just two; the intensity of the illumination hitting the surface of the solar panel (the number of photons) and the operating temperature of the solar panel (efficiency of the photon/panel interaction). The intensity of illumination is fairly intuitive, but what is interesting is that the efficiency of the solar panel goes up as the operating temperature goes down...the purpose of the MPPT circuitry is to adjust the solar panel operating point in response to changes in temperature to maximize operating efficiency.

Let's assume that we keep the two variables, light intensity and operating temperature, constant. When a solar panel is illuminated, with no load attached, the panel will produce a voltage (the open circuit voltage) however no power is produced because there is no current flow. If you attach a variable load (a variable resistor) across the solar panel, and measure the resistance as you adjust the resistor through its range and measure the corresponding voltage across the load, a graphic curve as depicted in figure 1 is produced. You need to use a little Ohm's law to calculate the current from the measured voltage and resistance. If you trace the plot of current vs. voltage, you notice that at zero current (open circuit) the voltage is around 5.5 volts, as the current flow increases (the load resistance decreases) the panel cannot produce enough current to hold the open circuit voltage level and the voltage drops down to virtually zero as the current demand through increases. This voltage drop is because there are not enough photons of light striking the solar panel but also the drop can be attributed to the internal resistance of the solar panel. This is

an interesting look at the solar panel performance and useful for understanding solar panel behavior under load at constant illumination and constant operating temperature.

Now, let's apply some more Ohm's law and calculate the power produced by the solar panel as a function of the panel voltage. Figure 2 is a plot of power vs. voltage.

Notice that the power output of the panel peaks at around 4.25 volts. So under the fixed illumination level and operating temperature, the maximum power point (MPP) is 4.25 volts. If we were able to keep the load conditions (or the panel operating voltage) at or around the MPP, then the panel would be operating at peak efficiency...and this is the whole point of the MPPT.

If we were to vary the temperature of the panel, another characteristic of a solar panel will come to light (pun intended), the panel efficiency improves as the temperature goes down. Figure 3 is a plot of three data sets collected at room temperature (24°C), in a refrigerator compartment (12°C), and in a freezer compartment (-12°C) of my house hold refrigerator. Notice the dramatic improvement of the solar panel output power when in the colder environment of a freezer.

MPPT Basics. To reiterate, in the most basic terms, the purpose of the MPPT circuitry is to adjust the solar panel operating conditions in response to changing panel temperatures to keep the panels operating at or near peak efficiency.

Figure 4 illustrates a simplified block diagram of the power components of a satellite. The left block represents the solar panels mounted on the satellite exterior surfaces that provide power for the satellite and replenish the battery/super capacitor power storage components when the panels are illuminated. The right block represents the batteries and/or super capacitors that provide power to the satellite during the eclipse portion of the orbit. Within this block is some sort of buck-boost power circuit that regulates the voltage from the battery to a level consistent with the operation of the satellite even if the voltage of the battery drops below the required voltage level. The power from the buck-boost circuit is connected to the satellite's central power bus for distribution. The upper center block represents the MPPT circuitry.

Within the MPPT circuitry are connections to temperature sensors and voltage sensors that are monitoring the operating conditions of the solar panels. The MPPT logic in turn toggles the solar panels on and off of the storage batteries in step with the sensor readings to keep the voltage output on the solar panels at or near the maximum power point (the sweet spot). Figure 5 graphically represents this MPPT process. When the solar panel voltage drops below a specific value, a FET switch opens to isolate the panel from the load. As the panel voltage rises under no load, the MPPT circuitry monitors the voltage rise. At the point when the voltage reaches a specific high voltage value, the FET switch is closed connecting the panel to the load. Continuing this cycle, as the panel voltage drops under the load, the MPPT control circuitry will open the FET switch when the voltage reaches the specified low value and the cycle repeats.

Simulating MPPT in the Classroom. The MPPT classroom simulator circuit diagram is depicted in figure 6, you will notice the similarity to the block diagram of figure 4. There are two parts to the simulator; the solar panel (this is a hobbyist solar panel and not the panels actually used on the satellite) and illumination source, and the MPPT circuitry with an interface

to a personal computer (figure 7). The circuit board layout for this project is illustrated in figure 8, the solar panel and light source LED sections are cut and separated from the main board for mounting in the ends of a 1 ½ inch PCV compression coupler fitting. This arrangement allows the illumination source to be controlled by limiting the exposure of the solar panel to ambient light. Figure 9 depicts the solar panel mounted on the PCB and installed in one end of the compression coupler. Notice the thermistor glued to the center of the panel. Figure 10 depicts the LEDs installed on the illumination PCB and mounted in the other end of the compression fitting. The connecting umbilical wiring provides 9-volts to the illumination PCB and returns voltage from the solar panel and signals from the thermistor to the MPPT main board.

Using the MPPT system. There are two separate exercises that can be performed using the MPPT classroom system; solar panel profiling, and MPPT exploration.

Solar panel profiling. To develop a profile of the solar panel, the MPPT circuitry is isolated from the solar panel and the load (a 10-turn pot) by removing jumpers (figure 11). A VOM is connected to appropriate test points, and a USB cable is connected between the board and a PC running a GUI written for this project (and used here to measure the temperature of the solar panel figure 12). The compression coupler assembly is brought to the desired temperature by placing the compression coupler assembly in convenient temperature environments, for instance room temperature (around 20°C) and in your home refrigerator food (around 12°C) and freezer (around -14°C) compartments. The load resistance is set at specific resistance intervals (I recommend 250 ohm steps), power is applied to the illumination board, and panel voltage is measured with the VOM and recorded in a data table. This process is repeated through the load resistance range (6K to 1K ohms). The data is entered into Excel and the graphing capabilities of Excel are used to graph the data. Likewise the profile is accomplished for the other temperatures of interest. The end result of this activity would look something like figure 13.

By looking at the peak power output points and inserting this information into a graphing calculator, the algorithm for the relationship between solar panel temperature and maximum power point is determined, the MPPT formula for the prototype system is shown in figure 13. This algorithm is entered in the PIC program that is used in the MPPT logic for controlling the system in the automatic tracking mode.

MPPT Auto Tracking Mode. The central component of this MPPT circuit is a PIC® microcontroller. The analog to digital converter (ADC) resources of the PIC are used to monitor the temperature of the solar panel and the voltage produced by the panel. The temperature dependent, calculated optimum power point (from the algorithm developed during the profiling of the solar panel previously) is used to determine if a FET switch is turned on or off to either isolate or connect the solar panel to the load. The hysteresis of the FET switch activation above or below the MPP is pre-set in software when the PIC is programmed. The MPPT circuitry is connected into the circuit by jumping J2 and J3. An oscilloscope is connected to the FET controlling signal at TP2 and to the panel output voltage at TP3 (figure 14). On power-up the system operates in the auto mode. The MPPT system behavior is illustrated in the oscilloscope screen shot in figure 15. The bottom square wave trace is the FET switching signal, the upper saw tooth wave is the solar panel voltage. If you compare the actual waveforms produced by the

MPPT circuitry in operation to figure 5 and the discussion earlier, you should be able to make the connection from the academic to the practical presentation of the MPPT concept.

The user can also observe the MPPT circuit behavior while responding to temperature changes by placing the compression coupler assembly in different temperature environments. The PIC is programmed to read the temperature at approximately 15 second intervals and make corresponding adjustments in the voltage hysteresis.

Manually Exploring MPPT. The GUI also allows the user to experiment with various high and low voltage settings to bracket the MPP and see the circuit's behavior (figure 16 and 17). The user can also monitor the MPPT circuitry as it responds to variations in load by adjusting the load resistor and observing the pulse width changes in response to the load changes and the corresponding change in the voltage slope when the panel is connected to the load.

Finally, the class can really get into depth of the MPPT operation and behavior by writing their own software to control the system.

Summary. There is a lot that can be learned from the study of the behind the scenes systems that make satellite communications possible, such as MPPT and Attitude Determination Experiment (Wobble). Additionally, there are lots of learning opportunities made possible by receiving and analyzing the telemetry data being transmitted by the satellites. From the academic and life-long-learner points of view, the Fox borne experiments are as important, if not more important, than the voice transponders they support. So I hope you will take some pass time to participate in the experiments, and become more proficient and capable satellite operators in the process.

As with the Wobble simulator project that was the subject of the companion article, this MPPT system project was made possible because of the generous support of the ARRL Foundation. I appreciate that they supported my own learning that resulted from the development of this project.

Questions? Let me know. Detailed operating procedures for using the MPPT classroom system are available, along with other detailed information that you will need to duplicate the project, is available from the author by a simple e-mail request to m Spencer@arrl.org. Availability of kits/boards and that kind of thing are being considered. Watch the AMSAT web resources for news.

CU on the birds!

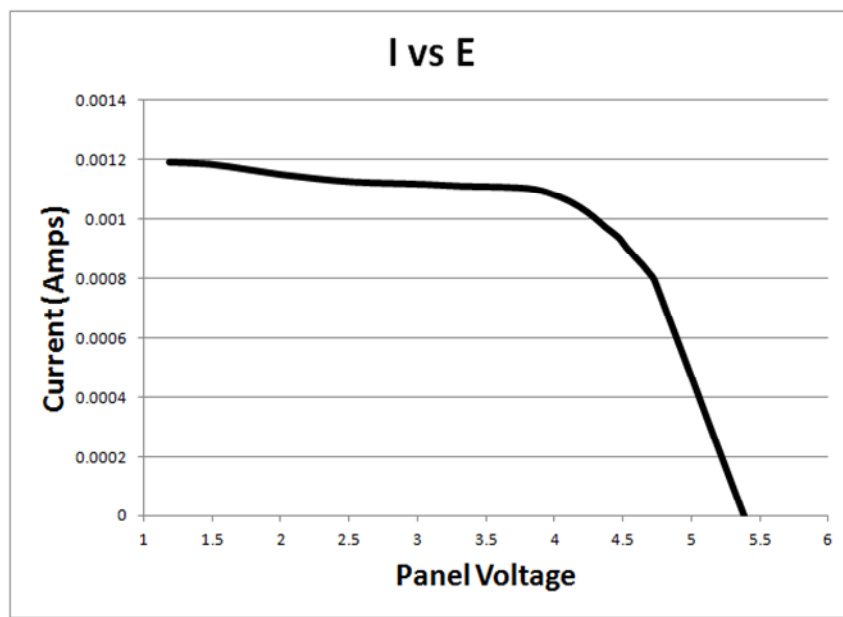


Figure 1.

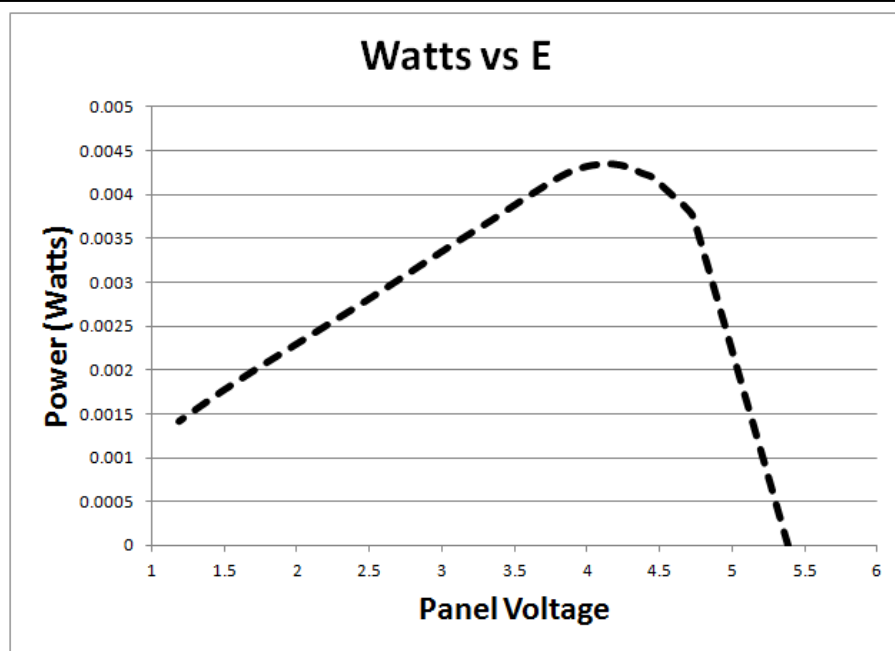
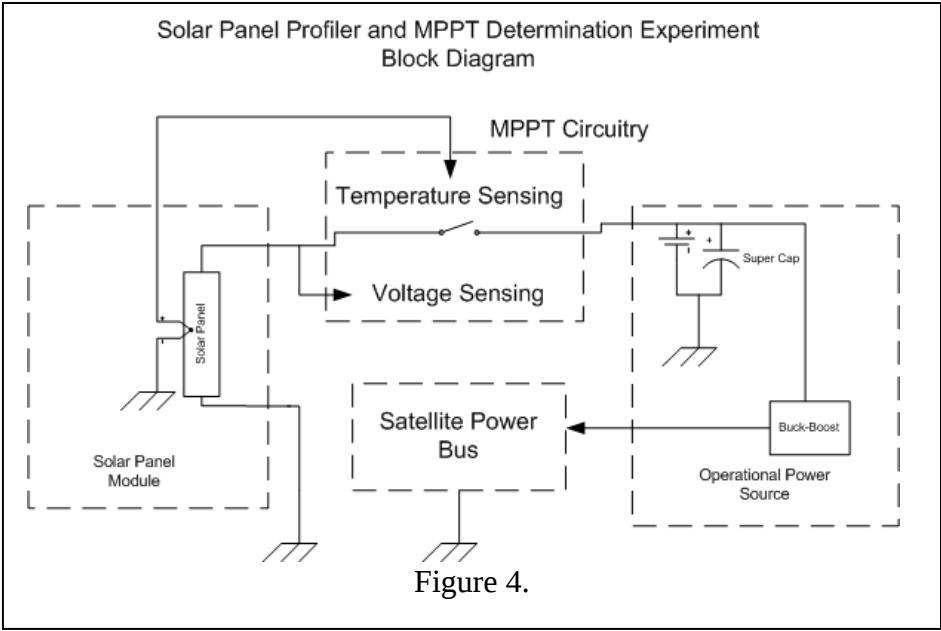
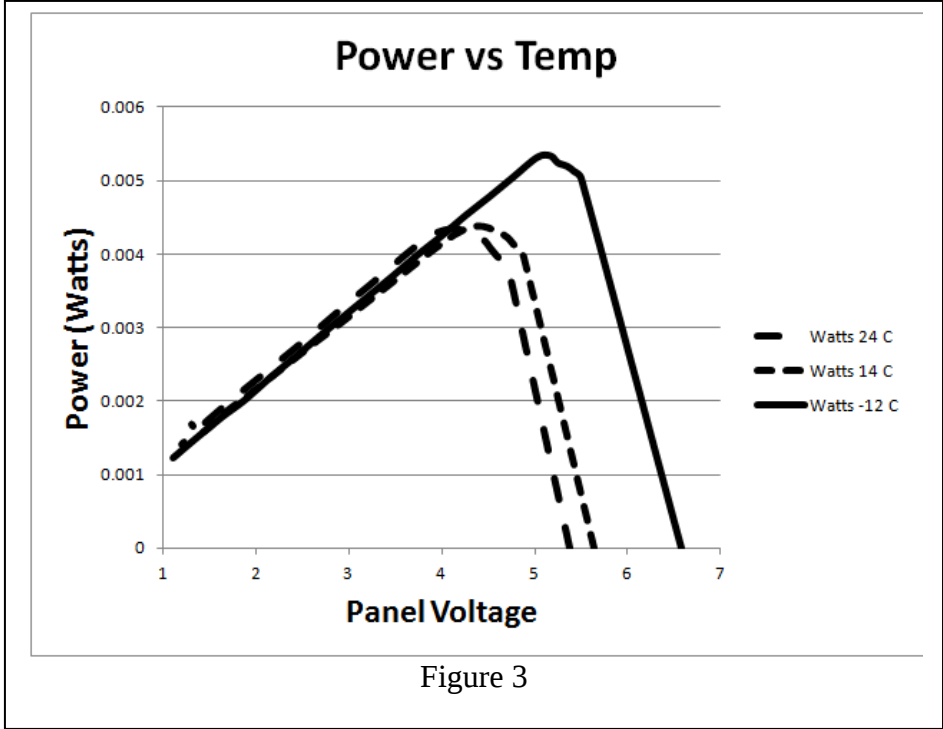


Figure 2.



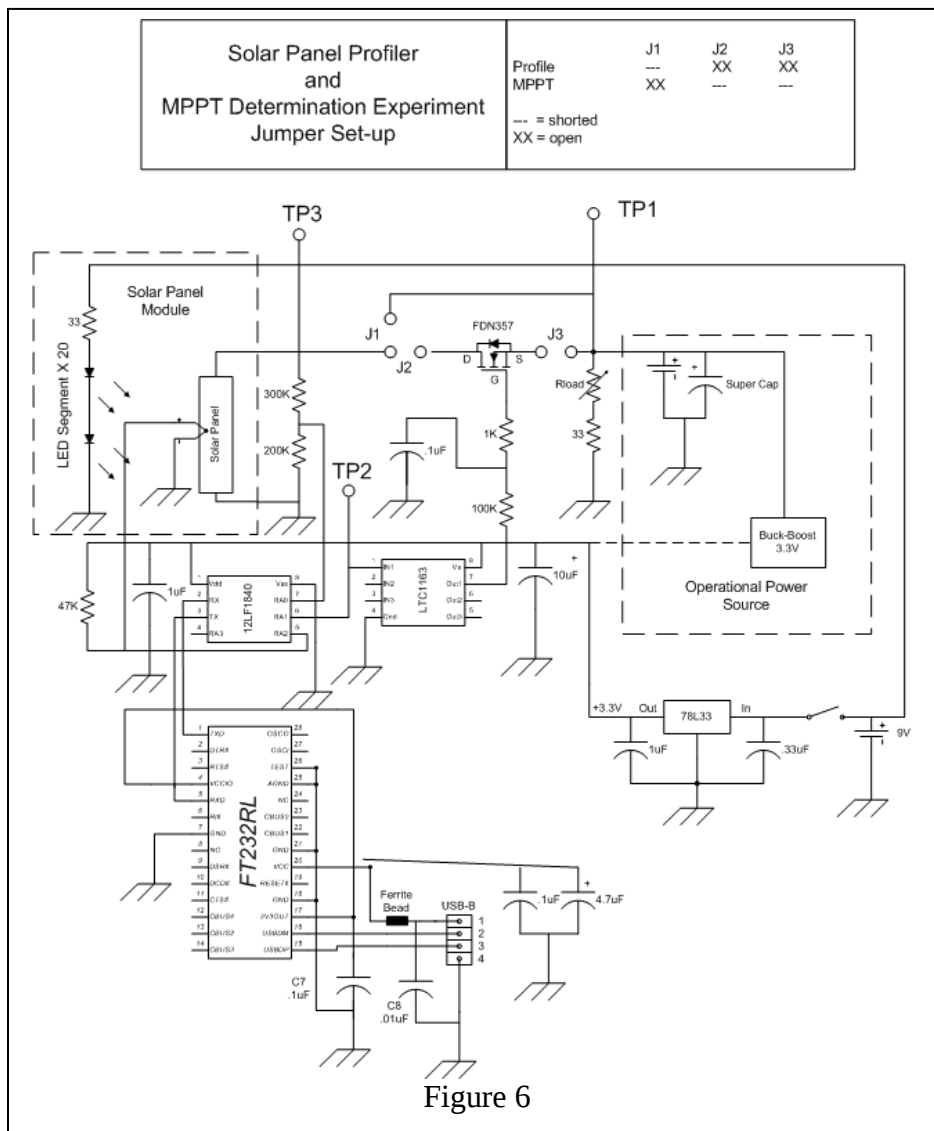
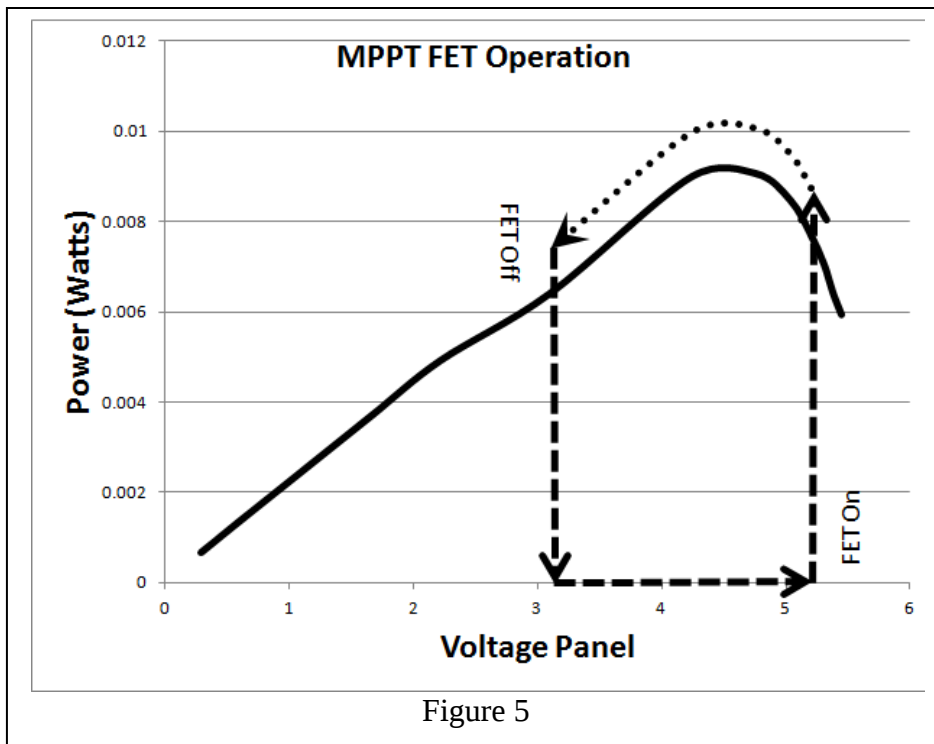




Figure 7

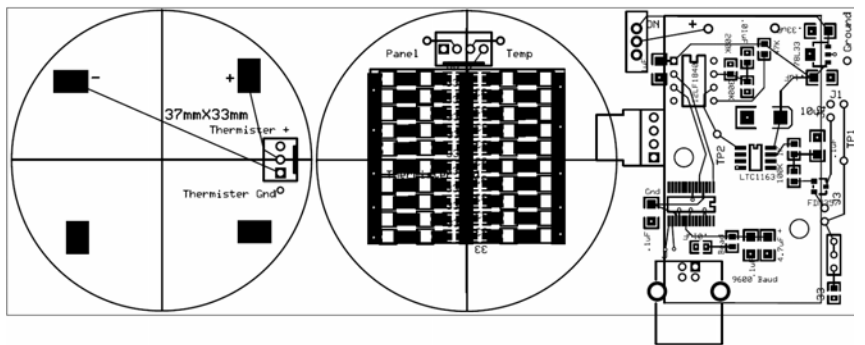


Figure 8

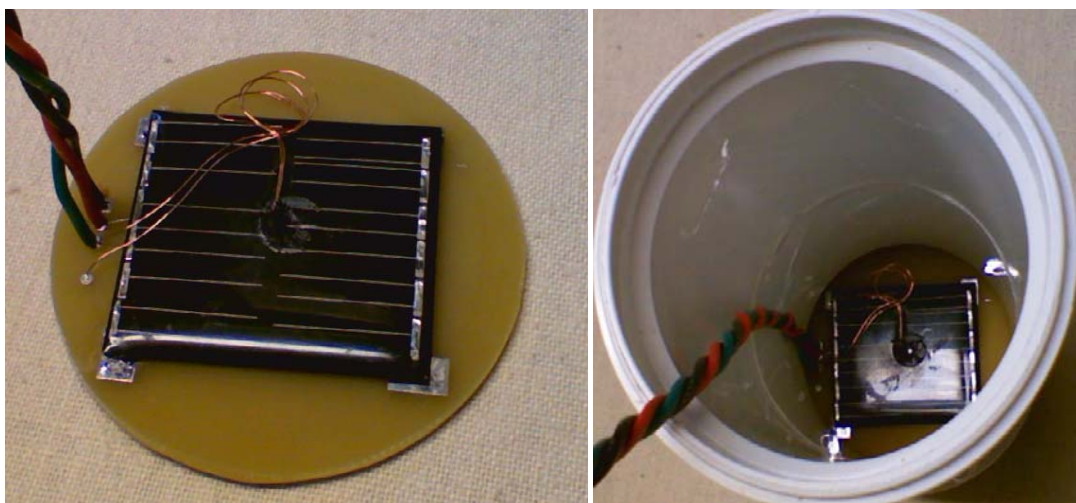


Figure 9

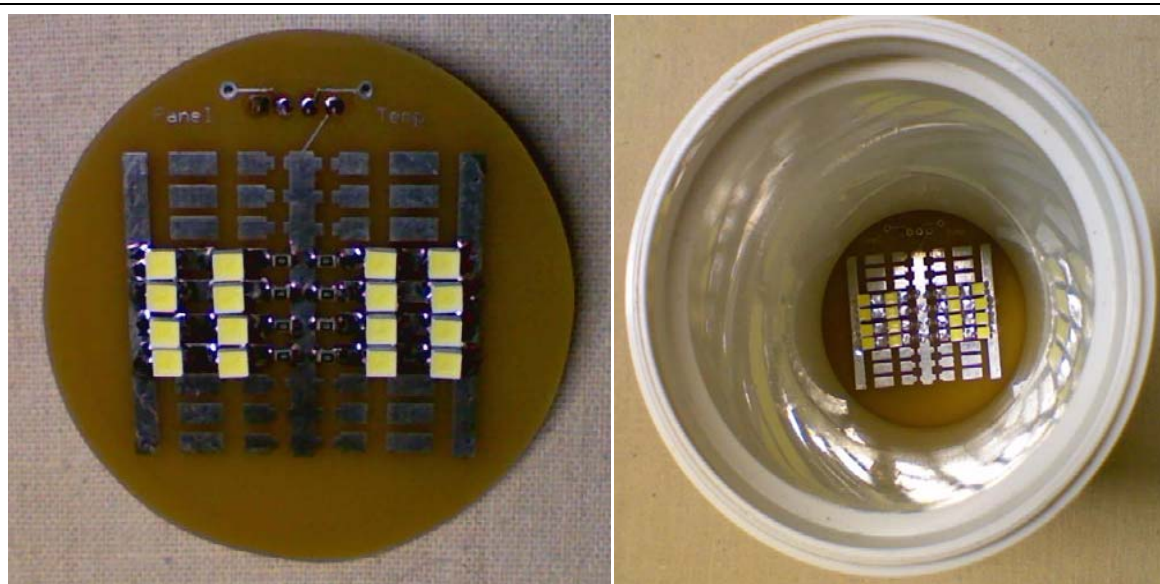


Figure 10

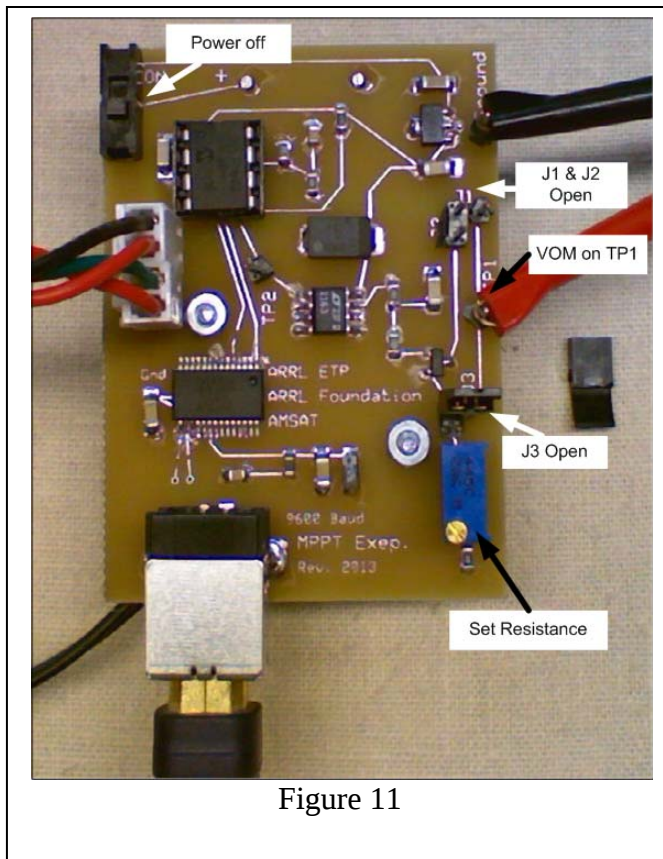


Figure 11

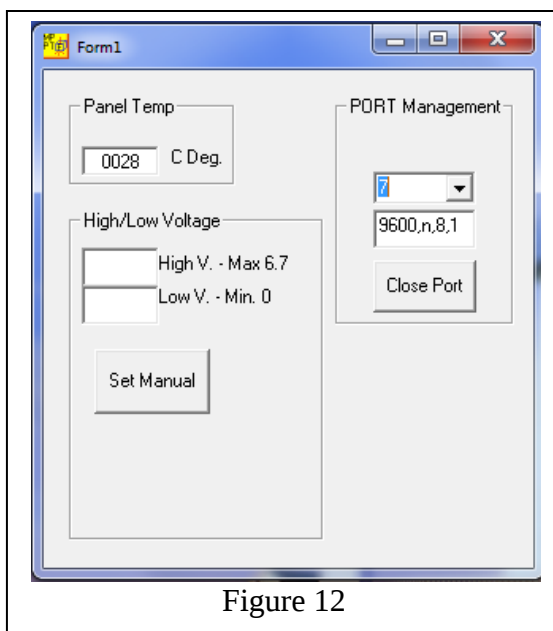


Figure 12

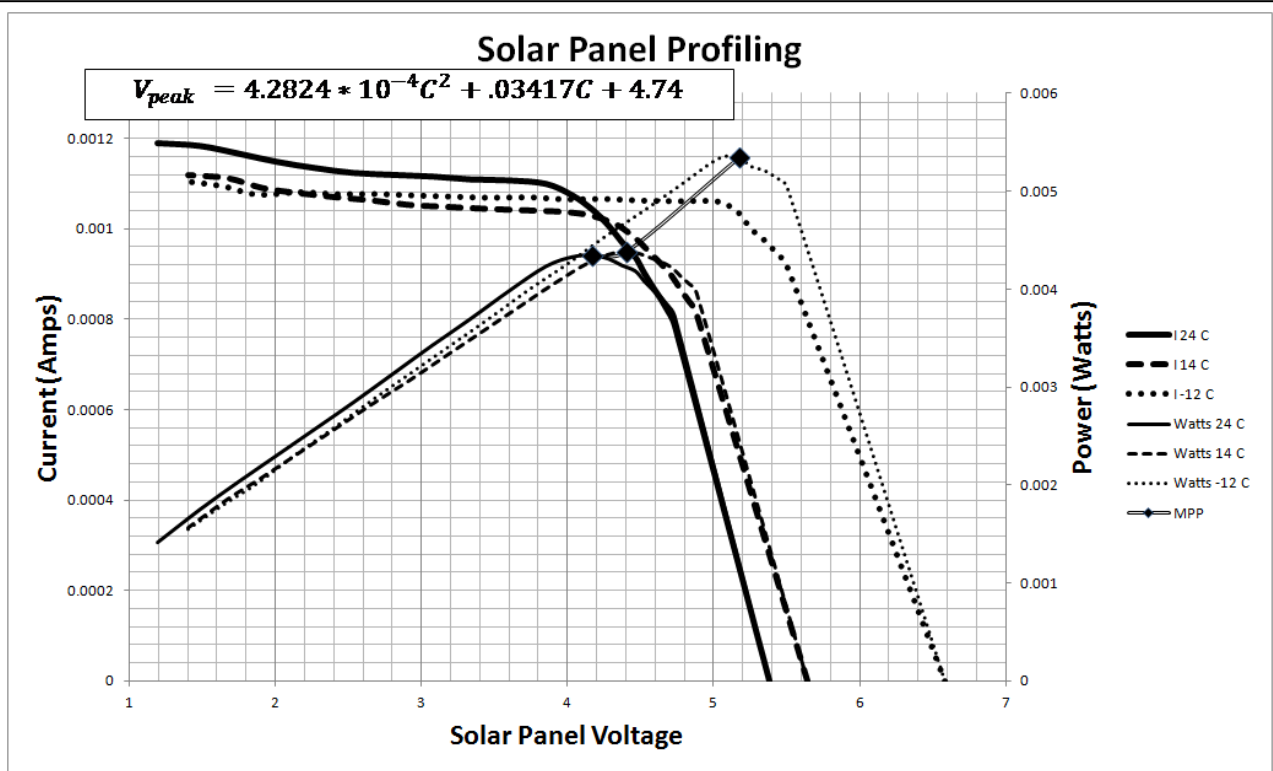
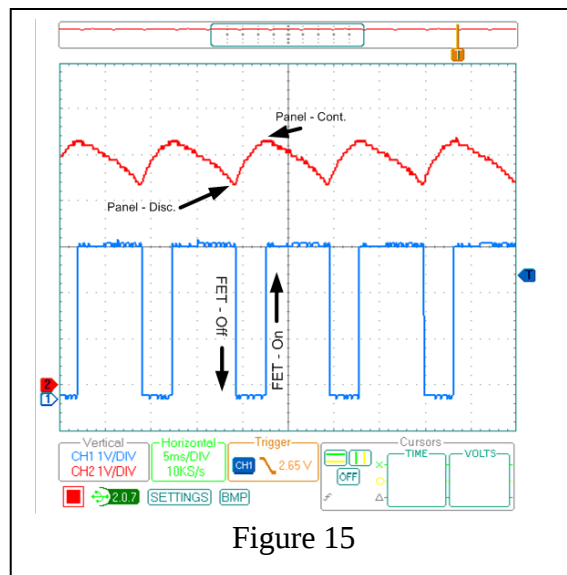
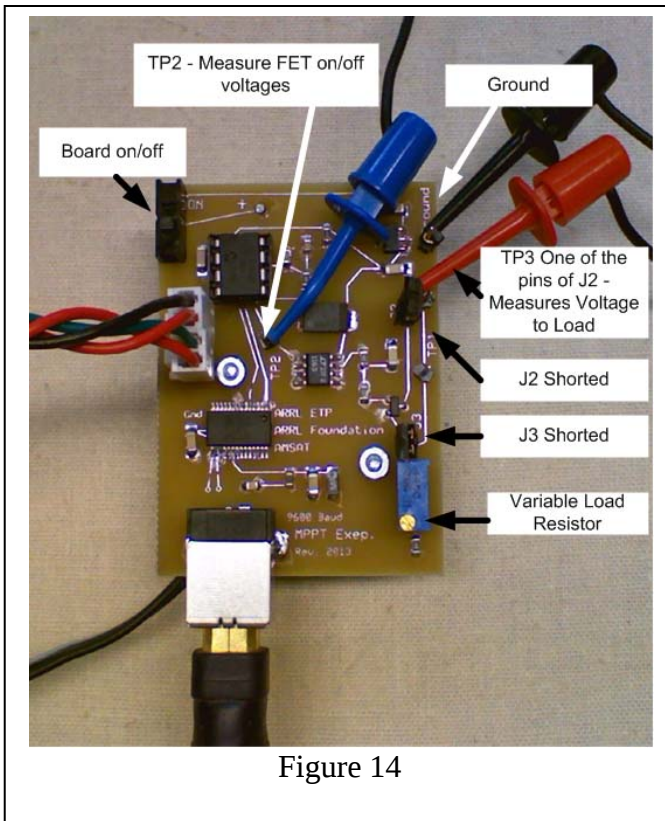


Figure 13



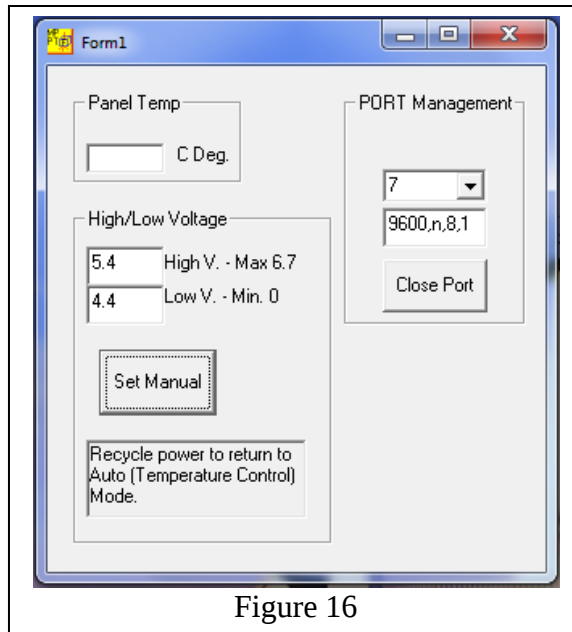


Figure 16

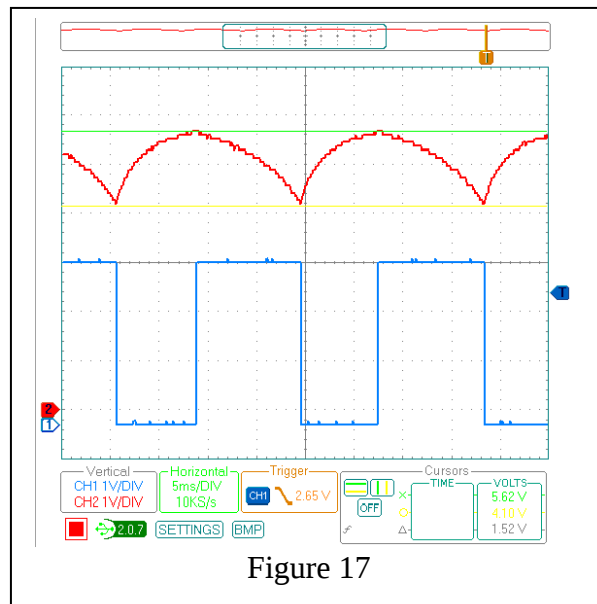


Figure 17

WRAPS Portable Satellite Antenna Rotor

By: Mark Spencer, WA8SME

ARRL Education and Technology Program

Recent AMSAT successes in competing for CubeSat launch opportunities, (Fox1A, Fox1B, and Fox2) which will carry experimental payloads and ham communications packages, signals a paradigm shift in future ham satellite efforts and gives a significant boost in the utility of CubeSats in the classroom. In this article I will introduce the WRAPS rotor system I designed to support working the Fox constellation of satellites. The acronym comes from the Attitude Determination Experiment (which I call Wobbler) to be carried on Fox1A, the Radiation Effects experiment to be carried on Fox1B, Antenna Pointing System.

My design goals for WRAPS included:

- Develop a portable, battery operated satellite antenna rotor system.
- The rotor would be easily duplicated using commercial-off-the-shelf (COTS) parts and simple hand tools with the minimum of machine work.
- Make a rotor that is an affordable alternative to the industry standard, the Yaesu G5500 (an excellent and proven rotor for base station operations).
- A limited duty rotor for small hand held satellite antennas in the ARROW and Elk class of antennas usable to receive Fox satellite signals.
- Target the school audience that wants to access the capabilities of the CubeSat systems (reduce the costs to the ARRL Teachers Institute Program) and the portable ham satellite enthusiast.
- Finally, to fulfill a bucket list goal.

The result; WRAPS:

- Runs off a 12 volt battery source (small sealed UPS batteries work fine).
- The cost of parts is approximately \$275 versus the \$1300 for the G5500 which includes all the associated cabling and computer interfaces.
- Includes an organic USB interface that works with SatPC32 and other satellite tracking software packages running EASYCOM protocol.

What WRAPS is not:

- It will not handle large antenna arrays, it is designed for ARROW and Elk class antennas only.
- It is not weather proof nor designed for 24/7 unattended operation.

This is a brief introduction of the WRAPS rotor, more detailed information that would be required to duplicate the project is available by a simple e-mail request to m Spencer@arrl.org. You will received all the relevant files including parts list with sources, schematics, software, construction details, templates for drilling holes and other simple metal work; in other words more detail than can be printed here.

Figure 1 shows the WRAPS in operation. It is mounted on a camera tripod. The PVC base sleeve slides over the camera mounting post of the tripod.

Mechanical. What makes the WRAPS possible is the proliferation of precision parts being manufactured for the robotics community. Figure 2 illustrates how these



Figure 1.

COTS parts are assembled to make the elevation part of the rotor. The EL rotor uses a .5 RPM DC geared motor that provides excellent torque at an affordable price. Over the years of toying with the idea of a portable rotor, I have tried many alternative motors from servos to steppers, but I found these obvious alternatives to a straight DC geared motor lacking in performance for one reason or other. You will notice that the construction is basically like building an “erector set” project. There are a couple of cut outs required in the aluminum channel chassis of the EL rotor, these cuts are easy to make with a hand hacksaw and clean up the rough edges with a metal file. There are eleven holes that need to be drilled in the rotor chassis box and some hacksaw, drill, and tap work on two metal brackets made from home improvement store aluminum stock supplies. Finally there are a couple of PVC pipe fitting parts that need some drilling.

The EL and AZ rotor position is determined by the value of variable wire-wound resistors that is connected to the motors by a pair of 36:50 ratio gears. The brackets for mounting the pot precisely for the gearing are made from circuit board material. The circuit board designed for this project includes the two brackets that are outlined and have pilot-hole locations marked (figure 3). These two brackets are separated from the main circuit board using a band saw.

The AZ rotor is a 1 RPM motor and mounted inside the rotor body enclosure along with the associated position pot (figure 4).

Electronics. A block diagram of the WRAPS circuitry is shown in figure 5. The completed circuit board is shown in figure 6. The heart of the WRAPS circuit is a PIC® microcontroller that, 1. receives positioning commands from the satellite tracking program, 2. translates those commands into rotor positions (ADC values), 3. reads the current rotor positions and determine if a position change is required, if so, which direction, 4. commands the motors to turn in the proper direction, 5. monitors the motors as they move, 6. stop the motors when they reach the commanded position, and finally 7. waits for the next position update. It sounds complicated, but if taken a step at a time, it makes sense. The PIC program is written in “C” and is included in the supplementary documentation.

There is a USB to serial converter included in the circuit that shows up on your computer as a comm. port. The position switches allow you to manually position the rotor motors. The calibration button switch allows you to make adjustments in the firm ware if the system gets out of “whack” for some

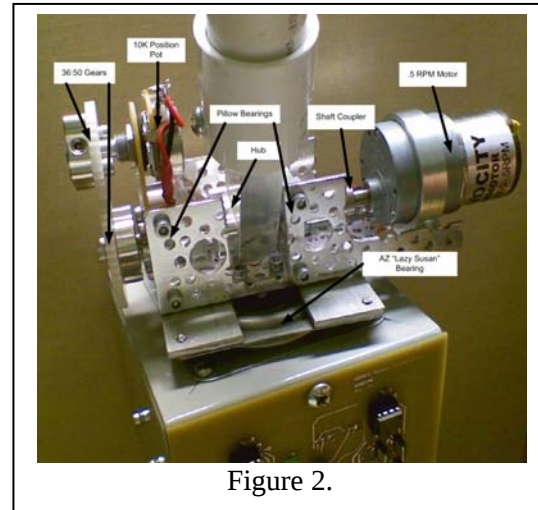


Figure 2.

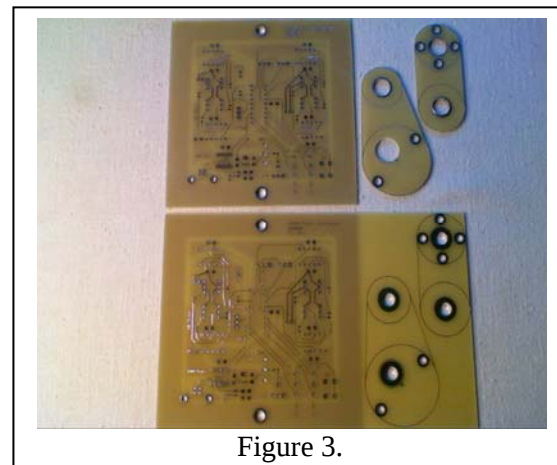


Figure 3.

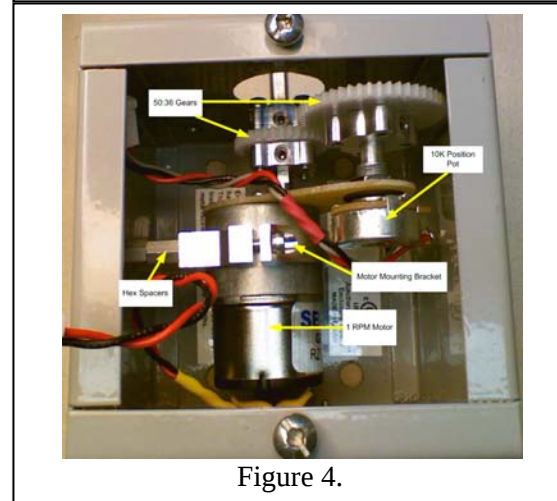


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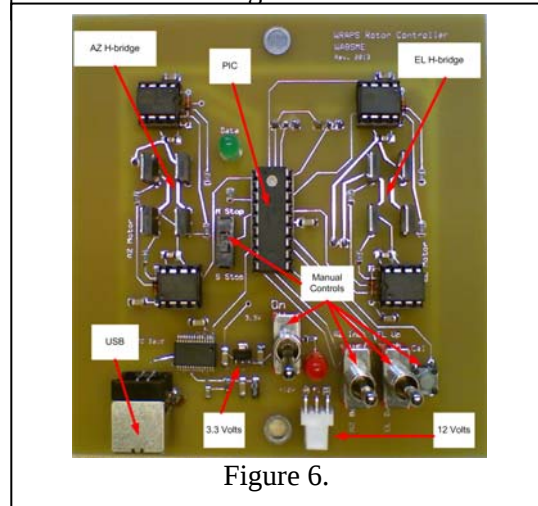
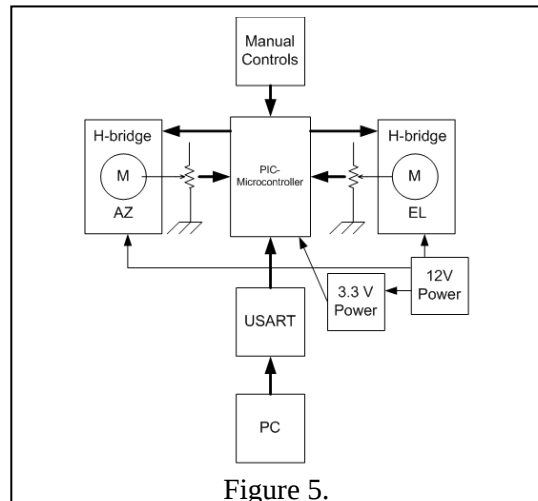
reason. You set the rotor to 0 degrees AZ and 0 degrees EL, press the CAL button, and that location is stored in the PIC. Conversely, set the rotor to 359 degrees AZ and 90 degrees EL, press the CAL button, and this stores the other stop in the PIC. The motors are controlled through the individual H-bridge circuits with pulse width modulation (PWM) produced by the PIC to set the motor speed. If you find that the motor performance is not to your liking, you can go into the software and change the PWM characteristics.

Operational considerations. Notice that the rotor is set up for 90 degrees maximum elevation. The ideal situation would be to have the EL rotor set up for 180 degrees maximum elevation to avoid the problem of flipping the antenna over when the satellite passes through the AZ stop or turn point. For instance, if the EL rotor is limited to 90 degrees elevation, and the AZ turn point is set to South, if a bird were to pass through your Southern horizon; at 179 degrees, the AZ rotor would have to rotate around 360 degrees to pick up the bird on the other side of South - 180 degrees. This would result in a loss of signal and is a problem with a fixed rotor installation.

This problem is mitigated in the WRAPS by its portability. There is a switch in the circuit that allows the user to select if the AZ rotor stop is North or South. With a little planning, if the satellite is going to pass through South, set the switch to a North turn point. Change the rotor setting to a North turn point in SatPC32 rotor setup, command a position to a known heading, pickup and rotate the rotor to that heading, and you're all set. Alternatively, if the satellite is going to pass through the North, set the switch to the South turn point and make the appropriate change in the SatPC32 rotor setup menu. This scheme simplifies the mechanical set up of the WRAPS, puts less strain on the EL rotor (the system could be mechanically modified to produce 180 degrees of EL rotation however), but also accommodates an Elk like antenna which would be difficult to operate with a 180 degree EL system.

Rolling your own. Though the design is intended for duplication by the interested ham, I anticipate there will be requests for boards, kits, and completed units. (I will be duplicating a number of the WRAPS rotors to support the ARRL Teachers Institute-2 Space program.) If you need to go a step beyond the request for the detailed information as suggested earlier, check the AMSAT store for availability of a limited number of complete WRAPS rotors (<http://store.amsat.org/catalog>). The units will be sold at cost of parts plus some delta that will be used to support current and future AMSAT CubeSat development efforts. Be assured you will be supporting the future of ham satellites if you go this route.

The WRAPS rotor project was motivated by the Fox CubeSat launches, but it was made possible in part by a grant from the ARRL Foundation and through an award from the YASME Foundation. I hope you will participate in the Fox CubeSats and join the ranks of the ham satellite enthusiasts. For more information, contact me at mspencer@arrl.org.



The Montgomery College Satellite Antenna Rotor Project

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This paper describes our experience learning how to use a Raspberry Pi computer to control a pair of Eagle Aspen rotors to develop an inexpensive azimuth and elevation antenna rotor system. We constructed a circuit board that interfaces between the Raspberry Pi and the rotors. Also, we wrote a small Python program that converts rotor position data to DiSEqC command bytes that are understood by the rotors.

Keywords: antenna rotor, DiSEqC, GPIO, PREDICT, Python, Raspberry Pi, serial port, tracker

INTRODUCTION

At the AMSAT-DC Workshop in March 2013, Dr. Tom Clark, K3IO, suggested that a pair consumer TV antenna rotors could be used to assemble an inexpensive azimuth and elevation rotor system. The rotors he suggested were the Eagle Aspen HDTV antenna rotor [Eagle] and Sadoun satellite antenna rotor [Sadoun] since they both use the DiSEqC command protocol. These rotors could be an alternative to the more expensive Yaesu G-5500 azimuth and elevation rotor system for tracking low-earth orbit satellites.

At the end of the Spring 2013 semester at Montgomery College, Prof. David Bern invited us to work on this project in a Summer workshop as part of the Robotics Club. This project was interesting to us since the knowledge and experience to be gained is applicable to robotics applications.

BACKGROUND

DiSEqC Protocol

The Digital Satellite Equipment Control (DiSEqC) is a digital communication protocol for use between a satellite receiver or a rotor controller and a remote device such as a satellite dish antenna rotor [DiSEqC]. The DiSEqC protocol was developed and published by the European satellite provider Eutelsat [Eutelsat 1]. It specifies how to send rotor control commands over the same cable that powers an antenna rotor. DiSEqC rotor commands are a sequence of bytes sent as a series of long and short millisecond 22 KHz tone bursts: a zero bit is sent as 1.0 ms tone burst followed by a 0.5 ms of silence; a one bit is sent as 0.5 ms tone burst followed by a 1.0 ms of silence (Figure 1). A command is followed by at least 6.0 ms of silence. These tone

bursts [Eutelsat 2] are then decoded by an embedded micro-controller that controls a motor within the antenna rotor. The command bytes are a sequence of eight bits; a ninth parity bit follows each byte. Command bytes are sent with their most significant bits first [Eutelsat 3]. The DiSEqC 6E five byte command specifies the angular position of a rotor in absolute degrees [Eutelsat 4].

DiSEqC Rotors

To better understand the DiSEqC protocol, we examined the waveform sent from Eagle Aspen controller to its rotor (Figure 2) on an oscilloscope (Figure 3). In addition, Prof. Bern devised a circuit (Figure 4) based on a design by Forrest Nimm [Nimm] that allowed us to directly examine DiSEqC commands with a logic analyzer [Saleae]. For example, a DiSEqC command to set the rotor to 000 degrees is shown in Figure 5. To our surprise, we discovered the Eagle Aspen rotor controller deviates from the DiSEqC standard by sending command bytes *without* their parity bits. We also learned that communications to the rotor is one way; the rotor does not acknowledge with a response. This simplified the project by just having to learn how to send DiSEqC commands to the rotor.

PROJECT

The goal of this project is to develop an inexpensive rotor controller to control two DiSEqC HDTV antenna rotors. Our rotor controller would emulate the LVB Tracker Box [G6LVB] that connects to the controller unit of G-5500 rotors [G-5500]. This means that our controller needs to understand the Easycomm protocol [G7UPN] or the GS-232 protocol [GS-232A]. Also, our controller needs to run stand-alone independently of a personal computer. Another requirement is that our controller and inexpensive antenna rotors are powered by 13 volts so they can be part of an outdoor amateur satellite ground station. We learned early in the project that an Eagle Aspen rotor can be powered by 13 volts but not a Sadoun rotor eliminating it for this project.

Raspberry Pi

The popular and inexpensive Raspberry Pi computer [Raspberry] is well suited for this project since it comes with hardware general-purpose input/output (GPIO) pins. The many books and the wealth of information on the Web made it easy for us to learn how to use and program the Raspberry Pi. In particular, the Adafruit Raspberry Pi tutorials Website [Adafruit 1] taught us how to install the Raspberry Pi Raspbian Linux distribution on an SD memory card. Raspberry Pi computers and its related accessories are readily available on the Web [Adafruit 2]. More importantly, the Python RPi.GPIO module available for it provides access to the GPIO pins in Python. In their book, Matt Richardson and Shawn Wallace gave us an introduction in Python on how to blink an LED with a GPIO pin [Richardson]. So it became a straight forward programming task of outputting DiSEqC rotor position commands to several GPIO pins. The Embedded Linux Wiki Website documents the GPIO serial input/output pins [serial 1] and showed us Python code to read from and write to a serial port [serial 2].

We discovered that networking is enabled by default when a Raspberry Pi is booted. Discovering its IP address is easy by connecting it and a personal computer to an Ethernet router [NETGEAR] and then by looking at the router's Web page that lists the IP addresses of devices attached to it. The personal computer is used to connect to the Raspberry Pi using ssh on Linux or Putty [PuTTY] on Windows. This scheme eliminates the need for a separate USB keyboard, USB mouse and an HDMI monitor connected to a Raspberry Pi or even using a USB serial cable [Adafruit 3] connected to the GPIO serial input/output pins.

Software

The software on the Raspberry Pi consists of a Python program and several shell scripts. The primary purpose of the Python program is to convert azimuth rotor and elevation rotor position data to DiSEqC command bytes that are output to several of the GPIO pins.

In tracker box mode, a USB to serial port adapter [Keyspan] is plugged into a USB port on the Raspberry Pi. A personal computer running a tracking program is then connected with a serial cable to the Raspberry Pi. The tracking program on the computer is configured to communicate with a rotor using the Easycomm or the GS-232A protocol. During a satellite pass, the tracking program sends position data over the serial cable to the Python program to immediately convert it to DiSEqC position command bytes being sent to the rotors.

In stand-alone mode, the Raspberry Pi uses the PREDICT satellite prediction program [KD2BD] to generate a text file of satellite pass data of a selected satellite. If the user is running Linux on a personal computer that is connected to the Raspberry Pi, then the user can then start PREDICT in one window (Figure 6) and start the gsat program in another window (Figure 7) to see the satellite ground track on a map of Earth. Also, gsat can display azimuth and elevation information in another window (Figure 8) showing the position where to point antennas from a ground station location during a satellite pass.

Interface Circuit

We needed an interface circuit that adds DiSEqC 22 KHz tone bursts in series with a 13 V power source. After some experimentation, we developed a simple circuit to do this using an audio transformer as shown in Figure 9. An AND gate gates the square wave from a free-running 22 KHz oscillator [oscillator] with DiSEqC command pulses generated by the Raspberry Pi (Figure 10). The transformer provides about a 10:1 voltage step down ratio; the waveform measured at the output of the transformer shows a peak-to-peak voltage of 600 mV (see Figure 11) which is within the DiSEqC specifications. Also, this waveform looks similar to the waveform of the output of the Eagle Aspen rotor controller shown previously in Figure 3.

The complete schematic of the interface circuit and parts list are provided in an appendix. In the circuit, three inverters are connected in parallel to provide sufficient current for the transformer. Note that the circuit has provisions for three rotors as suggested by Dr. Tom Clark, K3IO. The circuit was wired on a prototyping board specifically designed to be connected to the GPIO pins of a Raspberry Pi [Adafruit 3] with a ribbon cable (Figure 12).

The board includes a 2-pin connector to a 13 V power source and a 6-pin connector to the azimuth and elevation rotors.

Experience

The Eagle Aspen rotors are designed for light duty such as occasionally turning an HDTV antenna. At the September 2013 Silver Spring Mini Maker Faire, we demonstrated the Eagle Aspen azimuth and elevation rotors and a Raspberry Pi continuously for five hours. The azimuth rotor had lost its zero position. This was fixed by following the RESYNCHRONIZATION procedure in its manual [Eagle 2]. The elevation rotor presumably overheated since it stopped working near the end of the five hour period and then resumed working at a later day. In addition, we observed during testing and demonstrations that the rotors occasionally wander off as much 60 degrees while ignoring DiSEqC position commands for several seconds in the middle of a satellite pass. Our recommendation is that these rotors are fine for demonstrations and for casual amateur satellite work but not for serious satellite work.

Availability

All the source code, schematics, and documentation and other notes are available on The Montgomery College Satellite Antenna Rotor Project Website at

<http://code.google.com/p/mc-satellite-antenna-rotor-project/>

For convenience, a custom Raspbian image file is available with the project software installed. The user is given installation instructions on how to copy that image file to 4 GB or larger SD memory card and then how to boot their Raspberry Pi using an Ethernet router. A user guide is provided on how to use the Raspberry Pi software in tracker box mode or in stand-alone mode.

CONCLUSIONS

Learning how to interface consumer Eagle Aspen antenna rotors to a Raspberry Pi was an interesting project and, in retrospect, turned out to be pretty easy. About 550 lines of straightforward Python code was needed to be written to convert azimuth and elevation position data in absolute degrees to DiSEqC command bytes. The circuit to interface a Raspberry Pi to the Eagle Aspen rotors also was quite straightforward.

CONTINUING WORK

We plan to continue working on this project during 2013-2014 school year. We want to learn how to use motors, stepper motors and rotary encoders and learn how to interface them to a Raspberry Pi.

ACKNOWLEDGEMENTS

- Dr. Tom Clark, K3IO, for inspiring and advising us on this project
- Dr. Muhammad Kehnemouyi, the chairman of the Department of Physics, Engineering, and Geosciences at Montgomery College, Rockville for his encouragement and support
- Gilbert Mackall, N3RZN, for lending us his Yaesu G-5500 rotor and a Yaesu GS-232A computer interface

Questions, ideas, suggestions, and other comments are welcome by sending email to

mc.antenna.rotor.project@gmail.com

Daniel Albuquerque, *et al.*
Montgomery College
Rockville, Maryland
7 October 2013

FIGURES

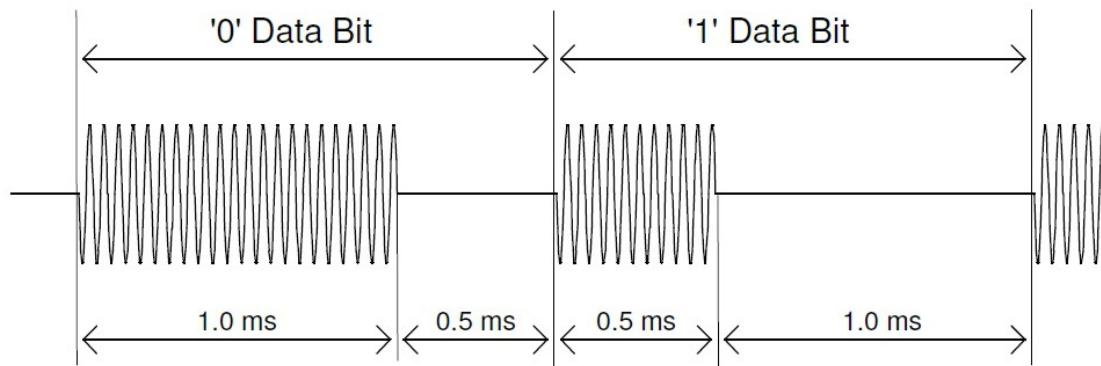


Figure 1: method of data bit signaling



Figure 2: Eagle Aspen Pro Brand International ROTOR

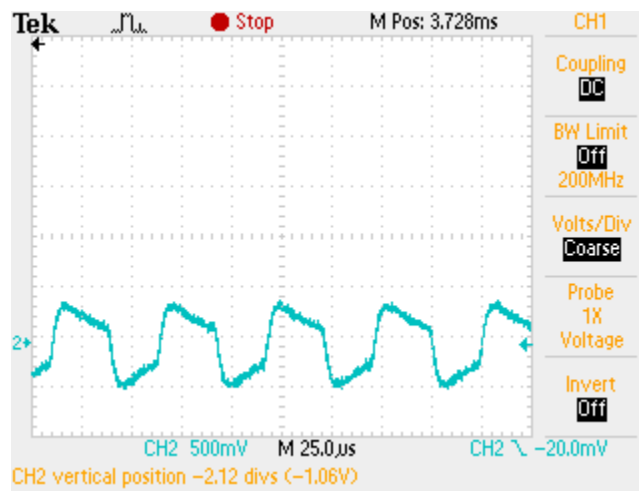


Figure 3: DiSEqC signal from rotor controller

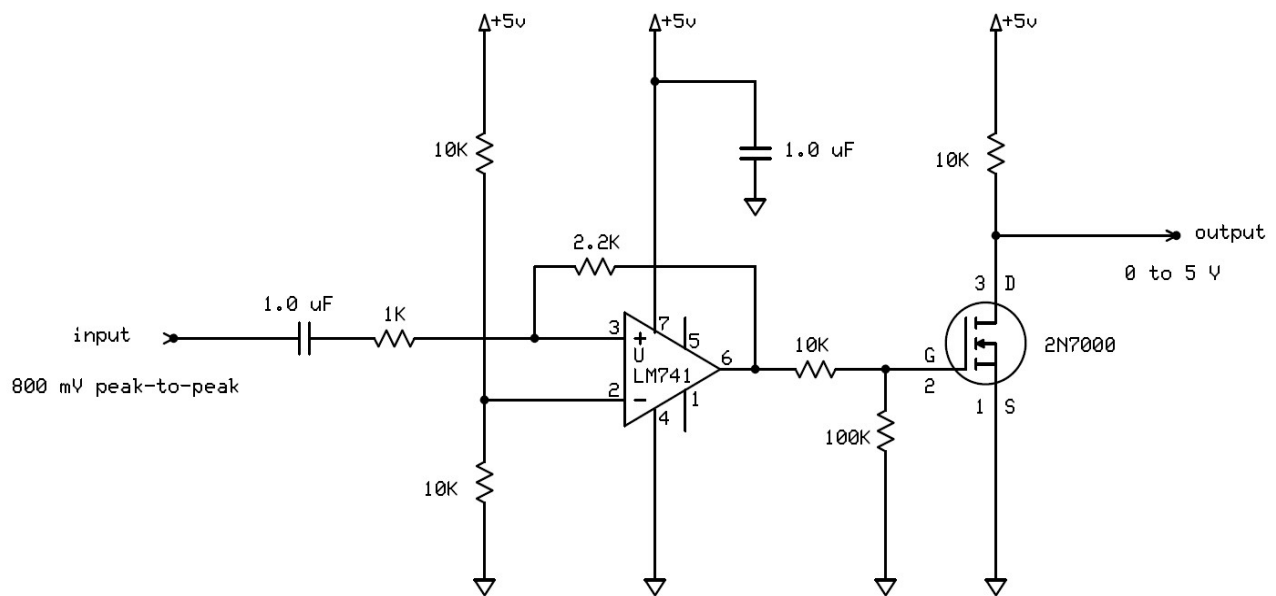


Figure 4: DiSEqC signal to TTL level converter

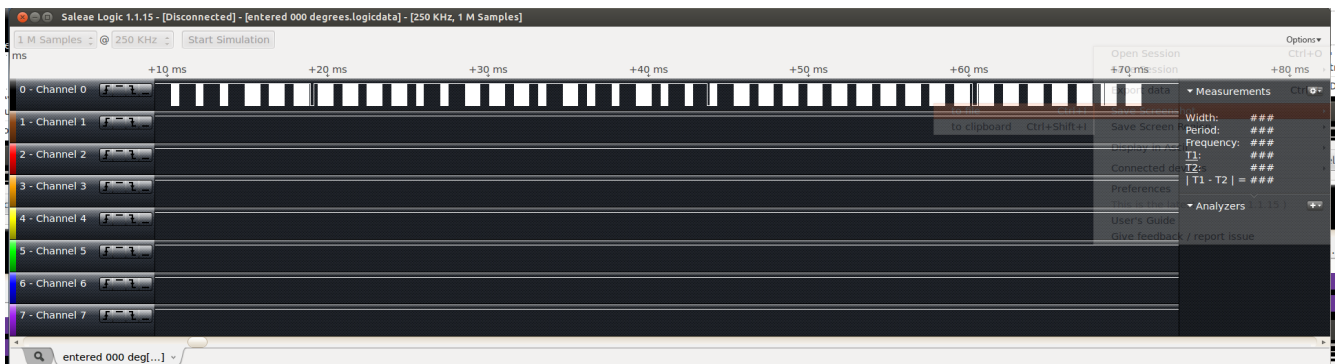


Figure 5: entered 000.0 degrees

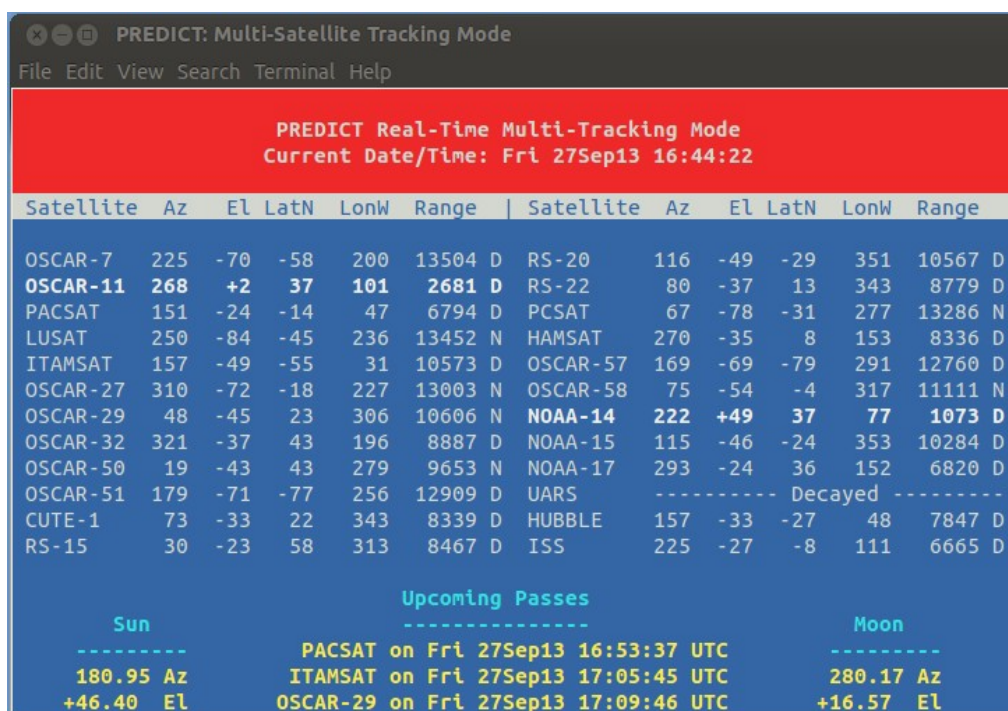


Figure 6: PREDICT

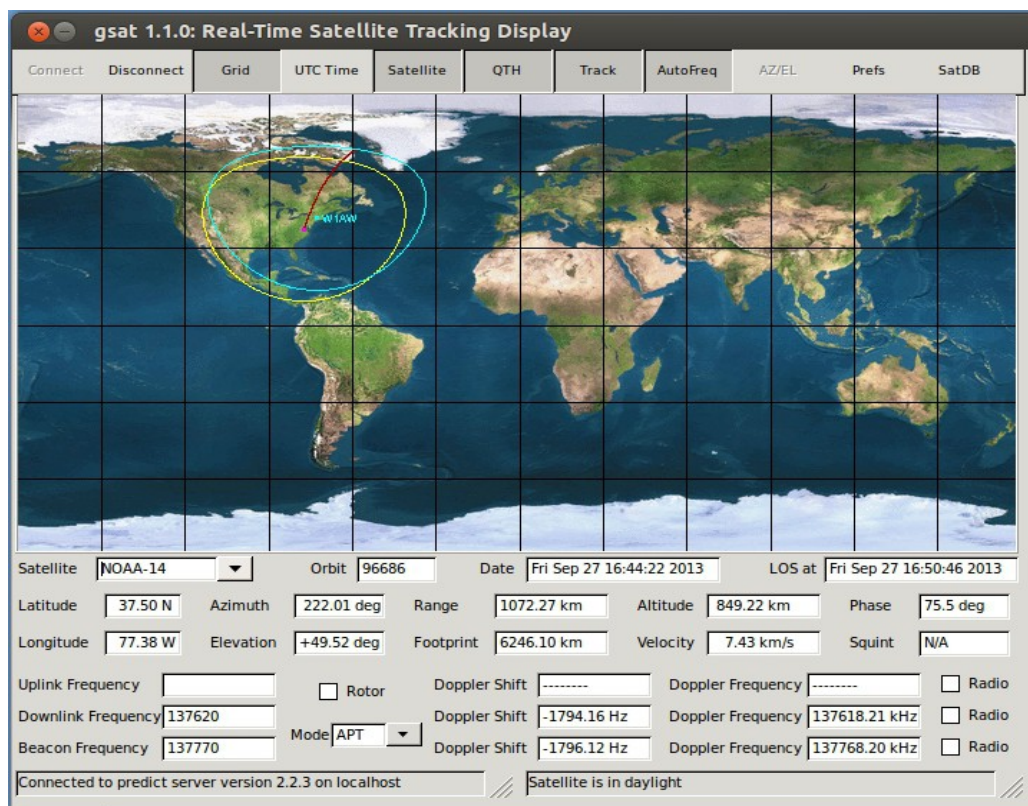


Figure 7: gsat

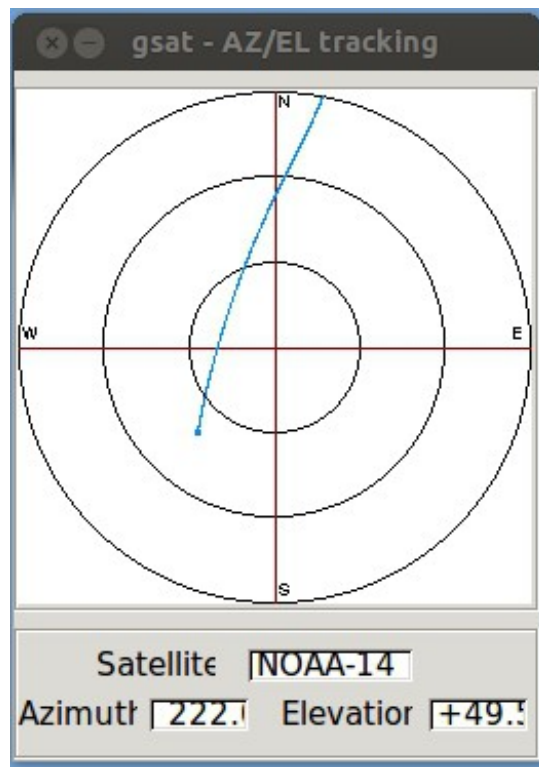


Figure 8: EZ-EL tracking

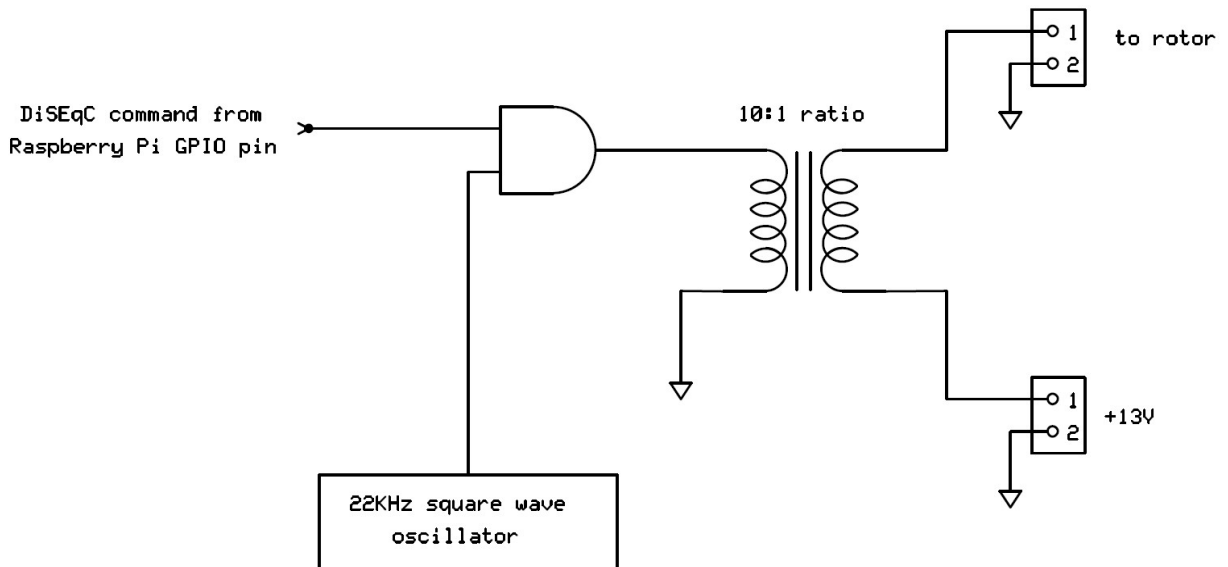


Figure 9: TTL level to DiSEqC signal converter simplified

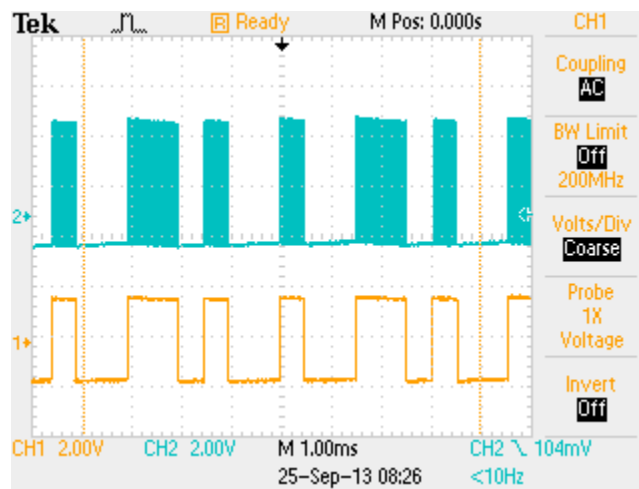


Figure 10: 22 KHz square wave gated by a DiSeqC command

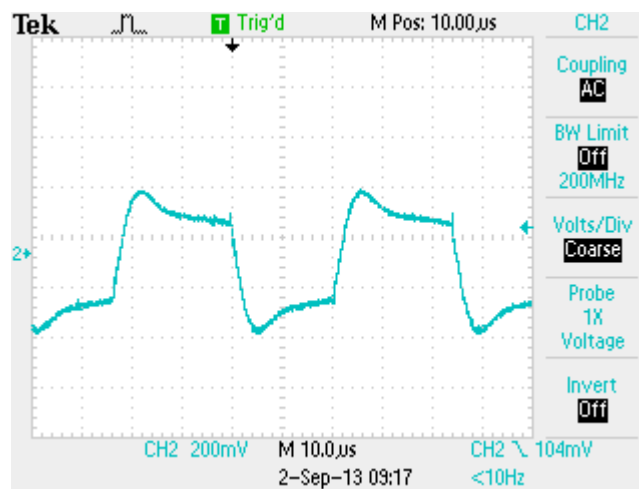


Figure 11: audio transformer connected to rotor

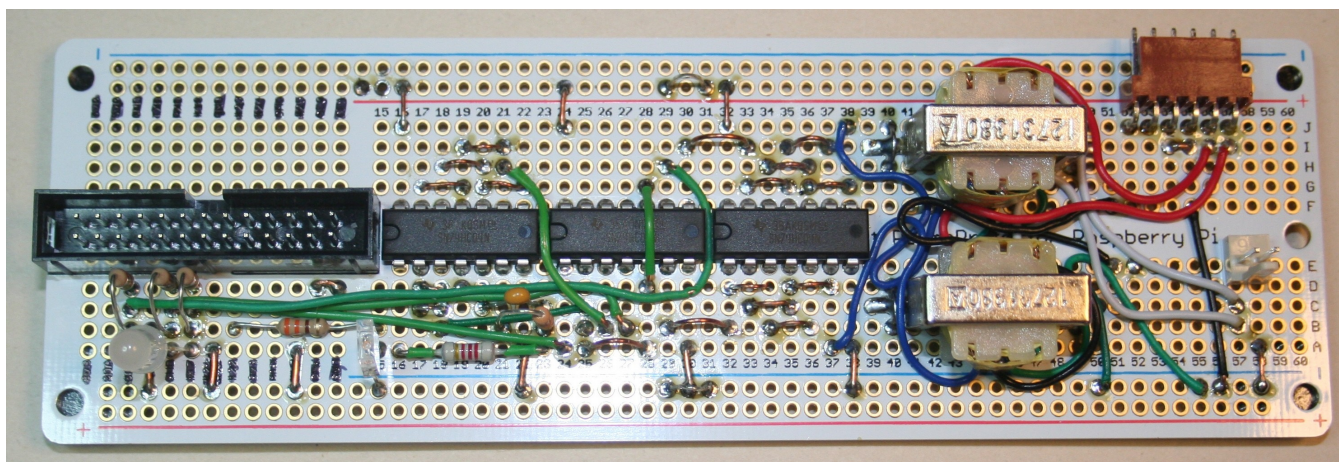


Figure 12: circuit prototype

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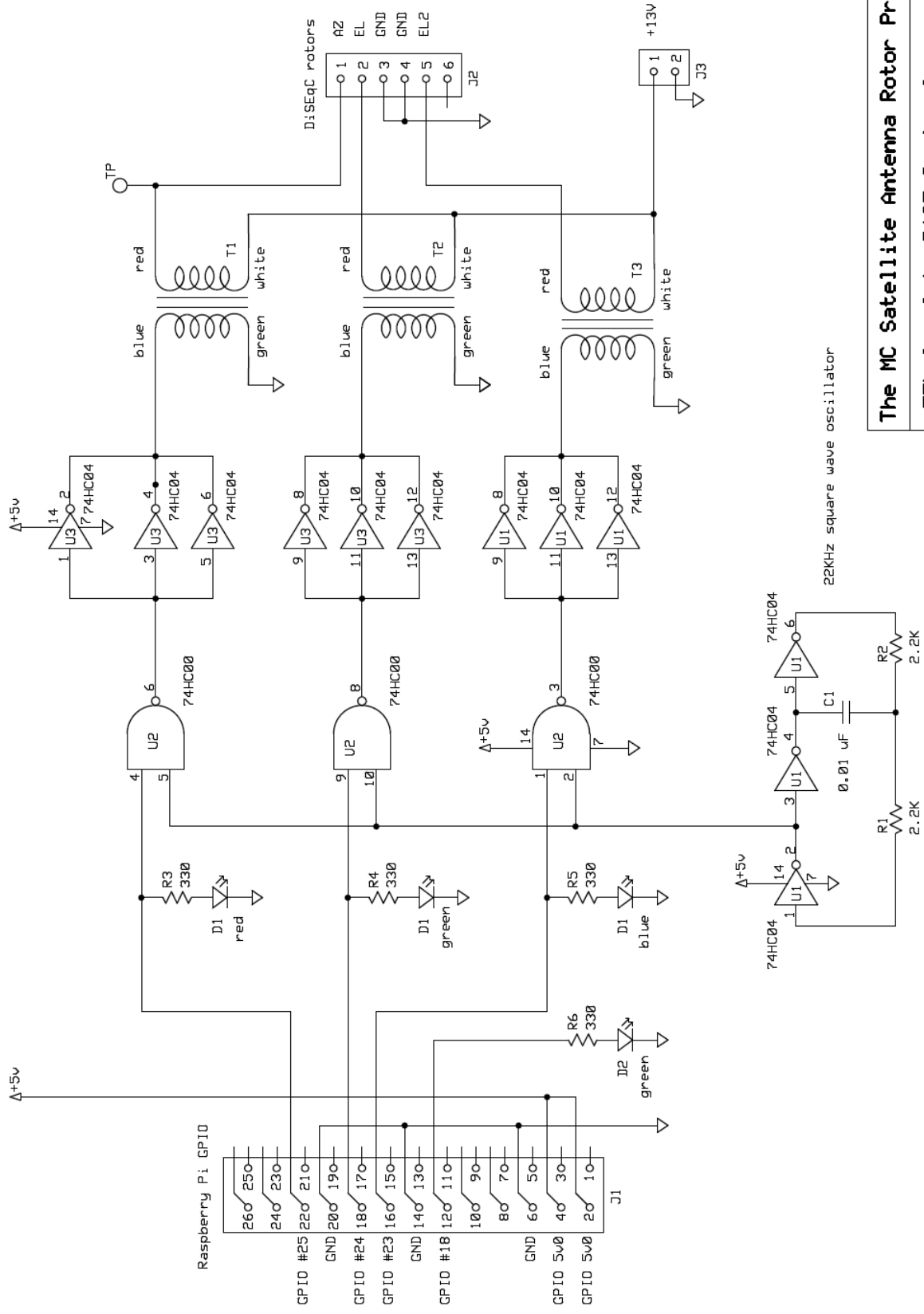
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Parts List

C1	0.01 uF	
D1	red	SparkFun COM-09264
D1	green	SparkFun COM-09264
D1	blue	SparkFun COM-09264
D2	green	LED
J1	Raspberry Pi	GPIO
J2	DiSEqC	rotors
J3	power	
R1	2.2K	
R2	2.2K	
R3	330	
R4	330	
R5	330	
R6	330	
T1	audio transformer	RadioShack 273-1380
T2	audio transformer	RadioShack 273-1380
T3	audio transformer	RadioShack 273-1380
TP	test point	
U1	74HC04	hex inverter
U2	74HC00	quad NAND gate
U3	74HC04	hex inverter

Side bar to: FUNcube Dongle and SDR - Radio Console for schools support

by: Hector L Martinez, CO6CBF
co6cbf@amsat.org

Abstract: *This short paper and accompanying power point presentation describes my personal experience running two marvelous pieces of engineering: FUNcube Dongle and SDR - Radio Console.*

In my University, sometimes we don't have the most motivating and encouraging instruments to make laboratory tests. So, SDR receivers and satellites have potential to be used to support theoretic phenomena in Engineering, Physics and Mathematics classrooms. In fact, they have supported it in a very good manner!



Professors and CO6CBF at the University's Technology Office after a successful kinetics experiment on HO-68.

Late on the last year, I had the highest honor of attending the 30th Annual Space Symposium in Orlando, Florida. Honestly, AMSAT Symposiums have been one of the most exciting times in my life and of course, an outstanding source of knowledge. Thanks again to everybody who have made

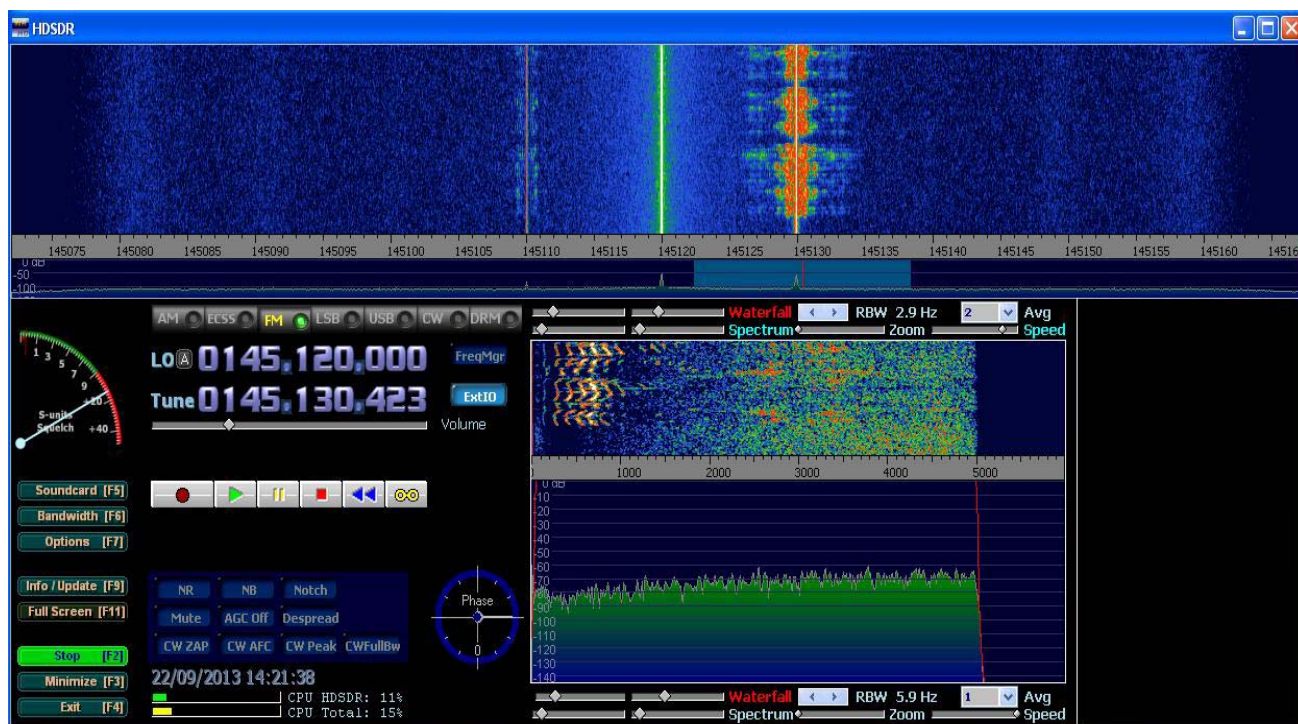
possible my trips, in special to the AMSAT Board of Directors; Patrick, WD9EWK and Clayton, W5PFG. I never will forget it!

During my trip, I received a lot of donations to improve my satellite station and I became a proud owner of one of the earlier versions of the FUNcube Dongle [1]. I believe it is the only FCD in my country! Thanks again to all my friends who generously donated stuff to improve my station! Never before operate on satellites hasn't been easier for me!



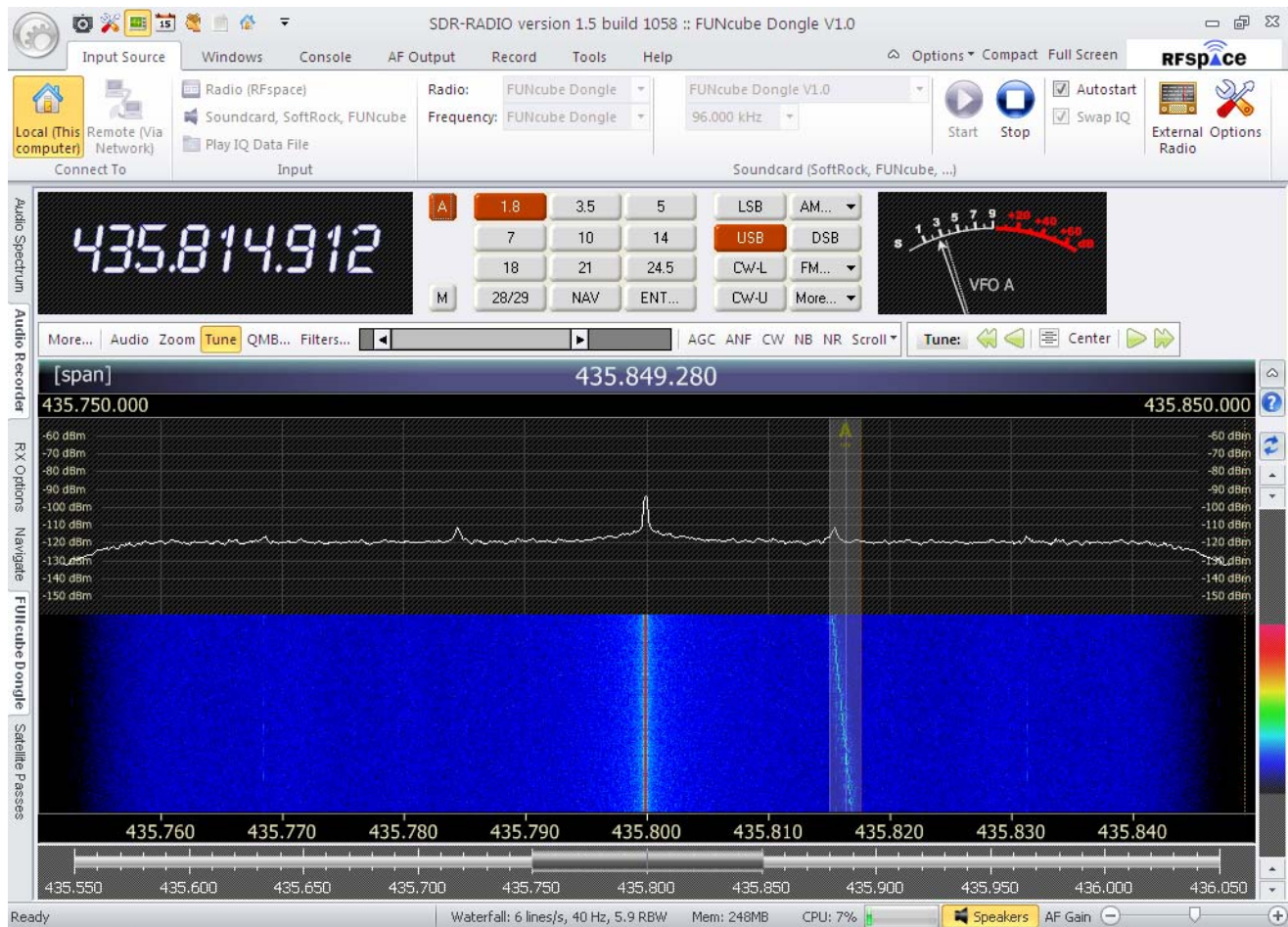
Right to left; Howard, G6LVB; Patrick, WD9EWK and Hector, CO6CBF posing with a donated FUNcube Dongle at the 2012 AMSAT-NA Symposium Banquet.

My first round with the Dongle was running HDSDR version 2.15; it needed an additional ExtIO file but it wasn't difficult to find on the web [2]. It was my first time playing with an SDR receiver and was amazing. I tried all the settings receiving the 2m local repeater (145.130 MHz) and after that I looked for HO-68 `s beacon. The receiver performed excellent!



Drew, KO4MA told me that he had heard good things about SDR - Console [3] for the FUNcube Dongles and I didn't wait to look for it. The file was 31.2 MB - a little complicated to download due to my limited Internet bandwidth but I asked for a bit of help and I got it.

So far a second round with the Dongle was running SDR - Console version 1.5. What a great combination! The software is just as important as the hardware we choose to get good performance from an SDR radio system.



The SDR - Console is not only an advanced solution for the FUNcube Dongles but also included a lot of very interesting features. It is being continually developed with new features added on a regular basis.

For FUNcube Dongle owners the console offers almost everything you need in one package:

- ❖ No license is required.
- ❖ Satellite support including:
 - ❖ Tracking.

- ❖ Doppler correction.
- ❖ NOAA weather image viewer.
- ❖ Full range of modes, filters and other DSP options.
- ❖ Recorder automatically starts when the currently selected satellite is visible (AOS) and ends when it is no longer visible (LOS).
- ❖ It can record the raw IQ (in-phase and quadrature modulator) data returned from the SDR radio or soundcard in a sequence of WAV files and the IQ WAV files can be played back to analyse received signals.
- ❖ You can see in the waterfall almost the complete transponder passband and all contacts in progress.
- ❖ The console supports remote connections via network with a very narrow bandwidth.
- ❖ It can send the IQ data to other programs. It is very useful to decode digital modes like JT65.
- ❖ You can make a Panadapter for non-SDR transceivers like FT-817 using FUNcube Dongles and the Console [4]; you can adjust the offsets simply entering the frequency difference and selecting up or down-converter.
- ❖ It has a very comfortable appearance.
- ❖ You can combine the Console and FUNcube Dongles with others radios to operate Full-Duplex, Full - Automatic controlled on satellites.

The future development includes:

- ❖ VITA-49 file/data format support for raw IQ recordings (version 2.2, October 2013).
- ❖ Recording scheduler (version 2.3).
- ❖ HF radio integration.
- ❖ Digital Modes.
- ❖ Rotator Controller.

I had made some satellite presentations in my University. Even running my homebrewed and primitive setup, I attracted some enthusiasts and now there is a guy already licensed and some getting ready for it.

On January 15th 2013 my University was celebrating "The Science Day", and I was invited to talk about Ham radio and satellites



CO6CBF`s experimenting satellite station at University

during the event. I made some contacts on FO-29; we listened for some beacons, and collected telemetry frames. It was my first presentation with my new gear and the Dongle caught all the attention. There were a lot of excited guys and Physics teachers loved to see the Doppler shift on the waterfall and the IQ analysis facilities!

The SDR Console allows an advanced analysis of all signals received in the 96 kHz Dongle's bandwidth and combined with you can record all the bandwidth as an IQ recording and playback it later in any time, any computer. It results in a very advanced instrument to support physics phenomena. Teachers and I chatted for a long time about how motivating and encouraging this kind of experiment could be for students. But due to the standard procedures, we could not figure out how implement it to support the practical class curriculum.

The solution came up a few weeks after that when I was noticed about my final school projects. I finished my college a few months ago and I had to present some projects as my studies' culmination. One of my final projects was for a class named: "Methodology of knowledge" and I found the way to forward my research to the influence of practical experiments on the skills and knowledge acquisition in engineering students. So, I had hardware, software, motivation and standard procedures to develop it. My goal was to figure out how students could use the SDR receiver in real time from the laboratories using the hardware and software already installed. Of course, the remote network connection was the solution. I installed the SDR - Console in my office computer at the University and I asked for a bit of help to some students to make the stress tests. We were listening for the 2m local repeater but the big problem was the limited bandwidth of our network. Even, we were using lower values for FFT size, resolution and Max lines/second in the SDR Server; more than three users connected turned the system unstable.

I told Mark, N8MH about my project and he suggested I update the SDR - Console to the new 2.0 version. I did so and it definitely worked better. It allows nine users to be connected with a decent audio quality. It looks like this new version is more compatible with a limited bandwidth network.

Guess what! The first attempt with satellites was receiving an ARISS contact! As we didn't



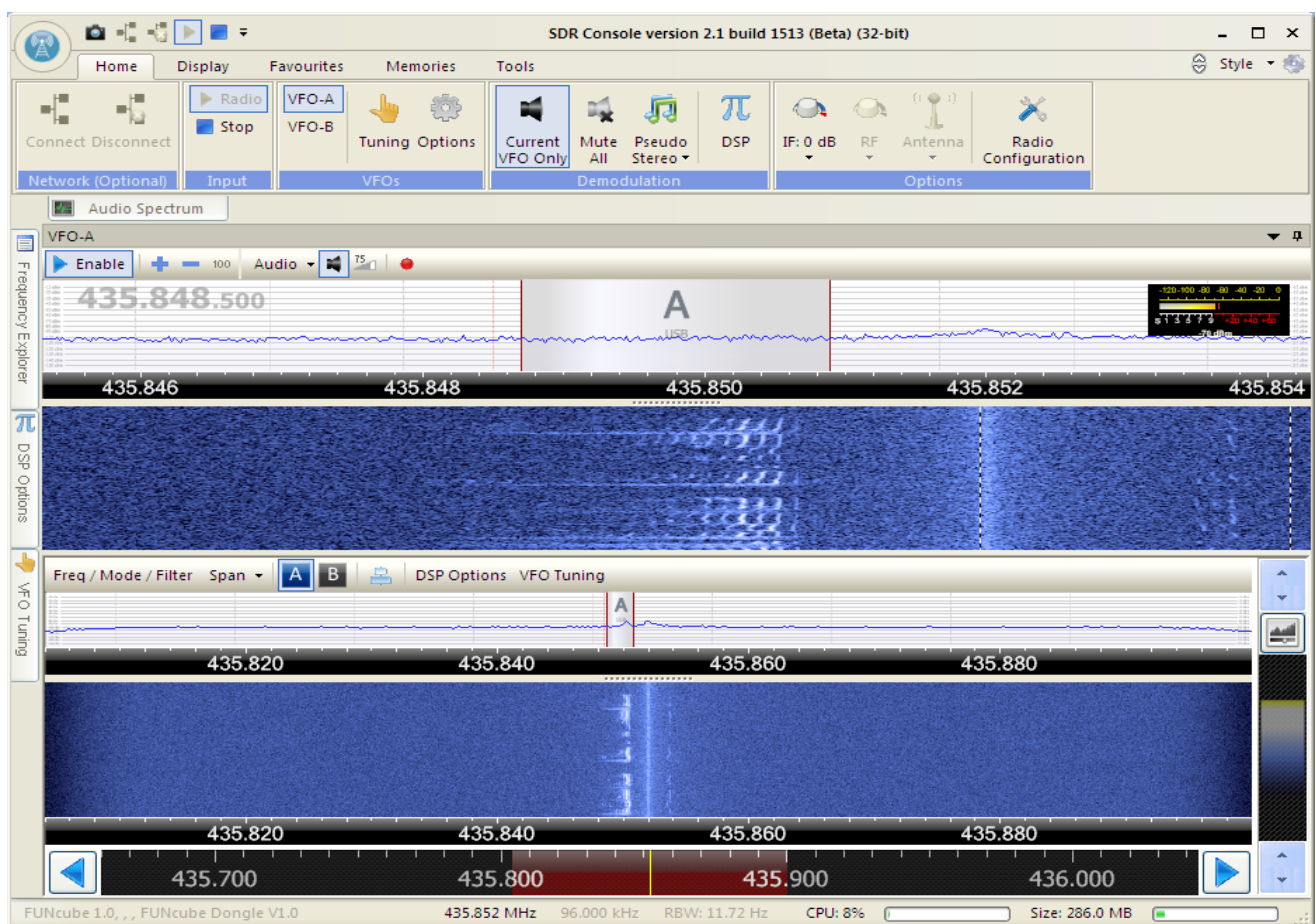
CO6CBF receiving an ARISS contact running FUNcube Dongle and SDR - Console v2.0.

have satellite antennas installed, we were at the technology office backyard, I was tracking the ISS with an ELK antenna while I was using a ThinkPad laptop connected to the University's network and some students were connected remote from the laboratory. What an experience!

On August 30th, 2013 the version 2.1 build 1494 (Beta) was released. I asked for a bit of help and I downloaded it. The 2.1 version has some very interesting features added. I was fascinated with the clean user interface, with no unnecessary features. Just all we need for a full satellite operation plus some earlier issues fixed.

After my first attempts with the new version and my FUNcube Dongle, I noted an issue in the console frequency correction. The ± 500 ppm range were not enough to correct the frequency shift on the receiver. The real frequency was around 8 KHz away from frequency shown on the waterfall. My Dongle is one of the earlier versions; I supposed it could be the problem. I contacted Simon Brown (the SDR - Console creator) and he fixed it quickly. SDR - Console is not only amazing SDR software but it also has a great support.

On September 18th, 2013; just a few weeks from the latest update, a new Kit (build 1513) was released.



Now, in my University, we are making plans to construct better Sat antennas. Meanwhile, we have homebrew omni antennas with homebrew preamplifiers and time to time under teacher requests I turn up the system to listen for ARISS contacts or listen for other satellites. Our dream is an ARISS contact!

The FUNcube Dongle makes a very nice satellite receiver with the SDR – Radio program. Needless to say that is a perfect combo for satellite reception and an outstanding tool to inspire next generations and support its curriculum making complex theories interesting and easy to understand. It is just incredible that a 150 kHz to 240 MHz and 420 MHz to 1.9 GHz all-mode receiver fits in the palm of your hand [5]. Thanks to Howard and Simon for this amazing combo!



Definitely, this simple and easy school project not only has made complex theories interesting and easy to understand for students but also has motivated other operators to turn their gazes skyward.

The Cuban Satellite Group (GROS) has been working very hard to promote Ham radio by satellites in our country [6]. We have seen how hard is to accomplish things in space and the amazing job of AMSAT since its birth. We appreciate AMSAT's efforts to keep Ham radio in space. We would like to help AMSAT with our small seed, but unfortunately we



Professors and CO6CBF in a satellite demonstration at the University's yard.

don't have funds for donations and we cannot help with a lot of things due to the ITAR restrictions. So, right now our only way to help AMSAT is promoting Ham radio by satellite and encouraging other operators to join us.

FOX-1 will be an enjoyable satellite for Cuban operators and a great tool to encourage new satellite enthusiasts. Unlike 70cm radios, almost every Cuban Ham has a 2m FM handy talky. So, everybody will be able at least to listen for FOX-1! We look forward to its successful mission!



Left to right; Felix, CM6FTV; Lazaro, CO6TW and Hector, CO6CBF at 2013 AMSAT Field Day.

Notes:

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Distributed Ground Station Network Receiver Node Design

by
Zach Leffke, KJ4QLP
November 2013

Keywords: Cubesat, SDR, FunCube Dongle, Beagle Bone Black, Ground Station Network

1 Introduction

With the increased access to space for Cube Satellite (cubesat) developers through the NASA Educational Launch of Nano-Satellites (ELaNa) initiative, the world has seen a steadily increasing number of cubesats deployed in the last decade. These spacecraft are being built by University, Government, and Commercial institutions for the purposes of performing Space-based research. The mission objectives of these cubesats are different from normal Amateur Radio satellites in that, instead of providing a communications relay service, they are collecting data from instruments that must be downloaded. This is significantly different in that large amounts of data must be stored onboard the spacecraft and then transferred to the ground during contact times with a control station. As data volumes increase, and data rates stagnate, a bottleneck effect is encountered whereby the cubesats are not able to transfer the required amount of data to the ground within existing communications protocols.

This paper will detail the design of a ground station receiver that can act as a node for a distributed ground station network. At the core of this design is a Software Defined Radio (SDR) receiver and a low cost embedded computer. The utilization of SDR technology allows for flexibility in the type of modulation schemes the receiver nodes will be capable of demodulating. With multiple ground station receiver nodes scattered around the globe, this network will allow for the use of existing low rate communications protocols, while allowing the total amount of data generated by a spacecraft to be increased. This is accomplished by increasing the amount of time available to access the spacecraft. The details of the higher level network design are outside the scope of this document, and the focus of this document will solely be on the design of the ground station network receiver node.

2 Problem Statement

Cubesats, like all spacecraft, rely heavily on wireless communications technology. As with most trends in wireless communication, there exists a demand for increased data rates. As

new cubesats are being developed and deployed there is a noticeable trend of increasing data volumes generated by the spacecraft. This increase in data volumes is primarily attributed to more sensitive scientific instruments with higher resolutions, increased duty cycle in the use of the instruments, and combining more and more sensors into a single payload.

Generally speaking the communications method used is not always a primary concern in the design of the spacecraft, and there is a tendency to simply duplicate methods utilized by previous missions. This is not altogether a bad mentality as the use of components with “flight history” is usually a good idea. Principal Investigators simply assume that they can use existing communications technology to get the data to the ground, and if they select a radio with flight history, they reduce the probability of mission failure. This is generally a true statement, however it introduces a problem.

To date the majority of spacecraft flown utilize Amateur Radio frequency allocations and protocols common to Amateur Radio operations [4]. The problem that exists is that Amateur Radio communications are generally limited by FCC Regulation as to the amount of spectrum a single user (or spacecraft) is allowed to occupy. Therefore, as data volumes for these space science cubesats increase, previously acceptable communications protocols that are bandwidth limited now become the bottleneck in getting the mission science data to the ground. This is compounded by the problem of the trend to build a single ground station for each spacecraft. The deployment of a number of networked ground station receiver nodes would increase access time to the spacecraft and ultimately allow for increased amounts of science data to be transferred to the ground.

3 System Overview

The heart of the design of the distributed ground station network node involves the selection of two key parts, a software defined radio (SDR) receiver and an embedded computer, aka a General Purpose Processor (GPP), capable of processing signals. All other components are developed around the SDR and GPP in an effort to make a robust, remotely controllable, and sensitive RF receiver capable of tracking and receiving signals from cubesats in Low Earth Orbit. A general system block diagram is shown in Figure 1 below.

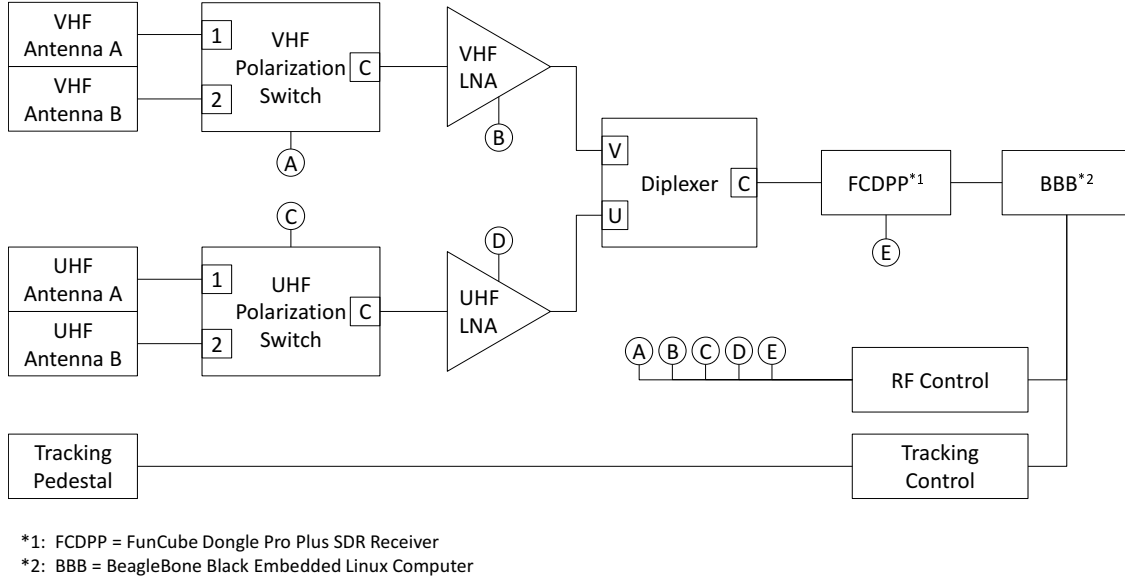


Figure 1: System Block Diagram

3.1 SDR Receiver

The selection of Software Defined Radio technology over a standard hardware radio is primarily due to the need for flexibility. Instead of building multiple hardware demodulators for existing cubesat protocols and then having to physically upgrade the system as new protocols become implemented on new spacecraft, this can now all be accomplished in software. Waveforms (applications that process radio signals in the software domain) can be written for specific spacecraft which conform to that spacecraft's specific modulation scheme, FEC scheme (if used), and higher layer communication protocol. Instead of having to physically travel to each node and install a new piece of hardware, the new waveform can simply be downloaded over the Internet to the receiver nodes, and then executed when there is a pass of the spacecraft.

The SDR receiver selected for this project is the FunCube Dongle Pro Plus (FCDPP) from Howard Long, G6LVB [6]. A number of candidate SDR systems were investigated, but for one reason or another were discarded. These SDRs include the RTL-SDR, the HackRF Jawbreaker, and the Universal Software Radio Peripheral Embedded Series from Ettus Research. Criteria for selection included receiver noise performance, interface methods, and cost. The FCDPP was ultimately selected due to a balance of cost (\$209.11 USD), a simple interface method (USB), excellent noise performance (more details in Section 3.4), and the specific attention in the design of this SDR towards its application for reception of LEO cubesat signals.

The FCDPP appears as a soundcard device to the host computer system. It passes the

16 bit Inphase and Quadrature (IQ) samples utilizing the 16bit, little endian, PCM interface of the soundcard to the host. The sample rate of the FCDPP is fixed at 192 kilo-samples per second (ksps). Because it is capturing both I and Q data at a rate of 192 ksps it is capable of capturing an instantaneous 192 kHz of RF Spectrum (± 96 kHz above and below the center frequency). Finally, the FCDPP has a Noise Figure of 3.5 dB in both the 2m and 70cm Amateur Radio bands[6]. More details about the control and signal processing software are given in Section 3.3.

3.2 Embedded Computer

Initially, the embedded computer selected for this design was the RaspberryPi Model-B rev 1 [10]. This system has a 700 MHz ARMv6 processor with floating point emulation, 512 MB of RAM, USB connectivity, 100 MB Ethernet, and is capable of running a full Linux OS distribution. This embedded computer has an extremely low cost of \$40.00 USD. However, the lack of a floating point co-processor, and the need to utilize floating point emulation for the necessary signal processing results in a system that simply does not have enough processing horsepower for SDR work. The author's only successful experiment with the combination of the Raspberry Pi and the FCDPP was a small application written in C that was able to stream raw samples from the FCDPP, via TCP/IP, to a host computer running an SDR waveform (GNU Radio). Unfortunately, this is not sufficient for the goals of this project. GNU Radio was successfully installed on the Raspberry Pi in an attempt to process signals from the FCDPP onboard the Raspberry Pi, however even the simplest GNU Radio waveforms caused the processor to bog down entirely when executed. After initial testing with the Raspberry Pi failed, the BeagleBone Black was tested next.

The final embedded computer selection for this design is the BeagleBone Black (BBB)[3]. The BBB has an AM335x 1.0 GHz ARM Cortex-A8 processor with a NEON floating point co-processor. From a processing power point of view this is sufficient for all necessary signal processing (with room to spare). In addition to its ability to process signals, the BBB also comes with a number of features needed for this system, including 512 MB RAM, a USB host interface (for connection to the FCDPP), 100 MB ethernet (for connection to the Ground Station Network via the Internet), and an external connector that carries up to 4 UART signals and a number of GPIO signals. Additionally, there are 2 GB of onboard flash storage with a high write speed (compared to the μ SD card) which will be useful for storing captured samples. It is currently running a full distribution of Ubuntu Linux v12.04 LTS installed on a 16 GB μ SD Card. GNU Radio has also been installed on this system and a number of waveforms have been successfully executed onboard the BBB.

3.3 Software

A number of pieces of software are required to realize the design of this system, and not all of them have been completed at the time of this writing. At the core of the design is the Software Defined Radio technology. The SDR Architecture chosen for this design is GNU Radio [5]. GNU Radio is a collection of signal processing blocks written in C and C++. Python is used to connect the various processing blocks and launch the waveforms, making it very easy to develop using GNU Radio.

To date, multiple waveforms have been created, using GNU Radio, that have been successfully executed on the platform. These waveforms include Narrow Band FM (NBFM) demodulators, AFSK1200 decoders (using multimon), SSB/CW demodulators, and direct sample capture flowgraphs. In all cases the connection to the FCDPP is the same. As described in Section 3.1, the FCDPP receives 192 kHz of RF spectrum and passes IQ data to the host. In all of the flowgraphs written so far, the samples are then converted into the GNU Radio Complex data type using the float to complex block. Because there is a strong DC component at the tuned center frequency, the FCDPP is tuned exactly 48 kHz *lower* than the desired center frequency of a spacecraft's downlink.

The complex stream is then passed through a Frequency Translating FIR filter that accomplishes multiple goals within a single block. First, it shifts the center frequency *higher* by 48 kHz to bring the center frequency of the target spacecraft back to the complex baseband center frequency of 0 Hz (i.e. it centers the satellites downlink for later demodulation). This method effectively avoids the DC component of the FCDPP and prevents it from interfering with the signal. Next the FIR filter decimates the 192 ksps stream by a factor of 4 resulting in a 48 kHz wide channel with the center frequency of the target spacecraft at the complex baseband center frequency of 0 Hz. A 48 kHz wide channel is wide enough to capture the entire positive to negative swing due to Doppler Shift for the 70cm band (around ± 12 kHz) and thus the entire swing for 2m as well. Since direct sample recording flowgraphs are one possible flowgraph this reduces the actual size of the recorded file by a factor of four compared to the a direct file capture at 192 ksps which is very useful when considering the limited storage capacity of the BBB. Also accomplished inside this block is the required filtering after decimation to avoid images. All of these flowgraphs were heavily based on the examples provided in [2].

Control of the FCDPP for the purposes of turning the internal LNA on and off as well as setting the center frequency of the device was accomplished using a small command line application called *fcdcontrol* written by David Pello, EA1IDZ. The detailed instructions for the installation and use of this utility can be found in [1]. The GNU Radio blocks mentioned in the previous paragraph as well the *fcdcontrol* were encapsulated in a GNU Radio Hierarchical Block (a hierarchical block is a GNU Radio block made up of sub blocks) for use with the previously mentioned waveforms.

The last major piece of software utilized by the system is the PREDICT satellite tracking

software written by John A. Magliacane, KD2BD. This software provides pass prediction capabilities (utilizing TLEs and the SGP4 algorithm) as well as tracking features for use in the receiver node. The benefit of this particular application is the UDP server feature which allows for third party software to be written that interfaces with the orbital tracking program. A python program is being developed at this time that will take the information provided by the UDP connection to the PREDICT application and apply the appropriate changes to the GNU Radio flowgraphs (to account for Doppler Shift) as well as to control the Tracking Subsystem in order to properly point the antennas.

Various other programs will be written or obtained as needed. OpenVPN will likely be the client utility used for secure access to the distributed Ground Station Network via Virtual Private Network (VPN) methods. Various scripts and server applications will be written that will allow communication to/from the central server of the Network. Time synchronization utilities will be necessary to lock the internal system clock of the BBB to the local GPS. TLE updating scripts will be generated that automatically download the most current TLEs from Internet sources. Surely a number of applications will be required that haven't yet been considered, especially when it comes time to integrate the nodes into the ground station network.

3.4 Noise Performance

Before going into the details of the design of the ground station network receiver nodes, it is important to determine the RF noise performance of the system to ensure it will be capable of receiving signals from spacecraft. In this section the overall system noise performance of the node is determined. With this information one can then perform a link budget analysis for potential target spacecraft to determine whether or not the link can be closed and the signals can be demodulated.

The key equation used to determine the overall system noise figure is the cascaded noise factor equation (Eq. [1] below from [7]). This equation takes into account the gain and noise factor of each component of the RF chain, excluding the antenna itself. Once the cascaded noise factor is determined for all of the components, the value is converted to a system noise temperature, added to the antenna noise temperature, and then converted back to the *System Noise Figure*. All variables in Eq. [1] shown below are in linear form and must be converted from the logarithmic (dB) scale before the computation is performed. The lower case nf indicates a linear term known as *noise factor*, whereas the capital NF is the logarithmic scaled *noise figure* (Eq. [5] shows the conversion equation between the two).

$$nf_{cascaded} = nf_1 + \sum_{i=2}^N \frac{nf_i - 1}{\prod_{j=1}^{i-1} g_j} = nf_1 + \frac{nf_2 - 1}{g_1} + \frac{nf_3 - 1}{g_1 g_2} + \frac{nf_4 - 1}{g_1 g_2 g_3} + \dots \quad (1)$$

In addition to the cascaded noise figure equation (Eq. [1]) a number of equations will be required in order to determine the overall system noise figure. Eq. [2] shows the conversion from the linear noise factor to noise temperature. In order to determine the system noise temperature the antenna noise temperature is added to the cascaded noise temperature as shown in Eq. [3]. For the antenna noise temperature a value of 100 [K] is assumed. Once the system noise temperature is determined, the system noise factor can be determined as shown in Eq. [4]. Finally, the overall system noise figure is calculated using Eq. [5].

$$T = 290 * (nf - 1) \quad (2)$$

$$T_{sys} = T_{cascaded} + T_{antenna} \quad (3)$$

$$nf_{sys} = \frac{T_{sys}}{290} + 1 \quad (4)$$

$$NF_{sys} = 10 * \log_{10}(nf_{sys}) \quad (5)$$

There are multiple components in the RF chain that need to be taken into account for the Noise Figure computation from the antenna all the way to the SDR receiver. Additionally, the ground station receiver node is designed to operate in the 2m and 70cm Amateur Radio bands. Therefore, two system noise figures must be computed, one for each band. The 2m component noise characteristics are shown in Table 1 and the 70cm component noise characteristics are shown in Table 2 below. There is a double hit with the passive devices, Insertion Loss (which can be treated as negative gain) and increased Noise Figure that is equivalent in value to the Insertion Loss.

Table 1: 2m Component Noise Characteristics

#	Component	IL[dB]	G[dB]	g[linear]	NF[dB]	nf[linear]
1	BNC(M)-N(F) Adapter	0.070	-0.070	0.984	0.070	1.016
2	LMR-400UF (6ft)	0.102	-0.102	0.977	0.102	1.023
3	N(F)-SMA(M) Adapter	0.070	-0.070	0.984	0.070	1.016
4	FLEX141, (9in)	0.030	-0.030	0.993	0.030	1.007
5	Pol SW, Coax Relay	0.100	-0.100	0.977	0.100	1.023
6	UT141, (10in)	0.033	-0.033	0.992	0.033	1.008
7	VHF LNA, AR ² P144VDG	N/A	24.000	251.189	0.500	1.122
8	UT141, (10in)	0.033	-0.033	0.992	0.033	1.008
9	Diplexer, 2m Branch	0.380	-0.380	0.916	0.380	1.091
10	SMA(M)-N(F) Adapter	0.031	-0.031	0.993	0.939	1.241
11	LMR-400UF, (4ft)	0.068	-0.068	0.984	0.068	1.016
12	SMA(M)-N(F) Pigtail	0.031	-0.031	0.993	0.031	1.007
13	FunCube Dongle Pro+		10.000	10.000	3.500	2.239

Table 2: 70cm Component Noise Characteristics

#	Component	IL[dB]	G[dB]	g[linear]	NF[dB]	nf[linear]
1	BNC(M)-N(F) Adapter	0.070	-0.070	0.984	0.070	1.016
2	LMR-400UF, (6ft)	0.186	-0.186	0.958	0.186	1.044
3	N(F)-SMA(F) Adapter	0.070	-0.070	0.984	0.070	1.016
4	FLEX141, (9in)	0.068	-0.068	0.985	0.068	1.016
5	Pol SW, Coax Relay	0.100	-0.100	0.977	0.100	1.023
6	UT141, (10in)	0.075	-0.075	0.983	0.075	1.017
7	UHF LNA, AR ² P432VDG	N/A	17.000	50.119	0.500	1.122
8	UT141, (10in)	0.075	-0.075	0.983	0.075	1.017
9	Diplexer, 70cm Branch	0.550	-0.550	0.881	0.550	1.135
10	SMA(M)-N(F) Pigtail	0.053	-0.053	0.988	0.939	1.241
11	LMR-400UF, (4ft)	0.124	-0.124	0.972	0.124	1.029
12	SMA(M)-N(F) Pigtail	0.053	-0.053	0.988	0.053	1.012
13	FunCube Dongle Pro+		10.000	10.000	3.500	2.239

Applying Equation [1] for each band to determine noise factor (linear scale) we have:

$$\begin{aligned}
 nf_{2m} &= 1.2395[linear] \\
 nf_{70cm} &= 1.3242[linear]
 \end{aligned}$$

We then apply equations [2 to 5], remembering to use the assumed value of 100 [K] for the antenna noise temperature. The resulting system noise figures, which are quite acceptable, are shown below.

$$\begin{aligned}
 NF_{2m} &= 2.00[dB] \\
 NF_{70cm} &= 2.22[dB]
 \end{aligned}$$

4 Receiver Node Design

As depicted in Figure 1, the ground station network receiver node design consists of RF interconnections, control, and power signals. For the physical implementation of the system, five subsystems have been built to realize the design. Each subsystem is housed in its own external enclosure to make the system somewhat modular to allow for future improvements without having to rebuild the entire system. These subsystems include the Main Computer and Radio Subsystem, The Antenna Subsystem, The RF Front End Subsystem, the Tracking Control Subsystem, and the Power Supply Subsystem. The following section breaks down the design of each subsystem. Figure 2 shows the interconnection of the subsystems' External Enclosures.

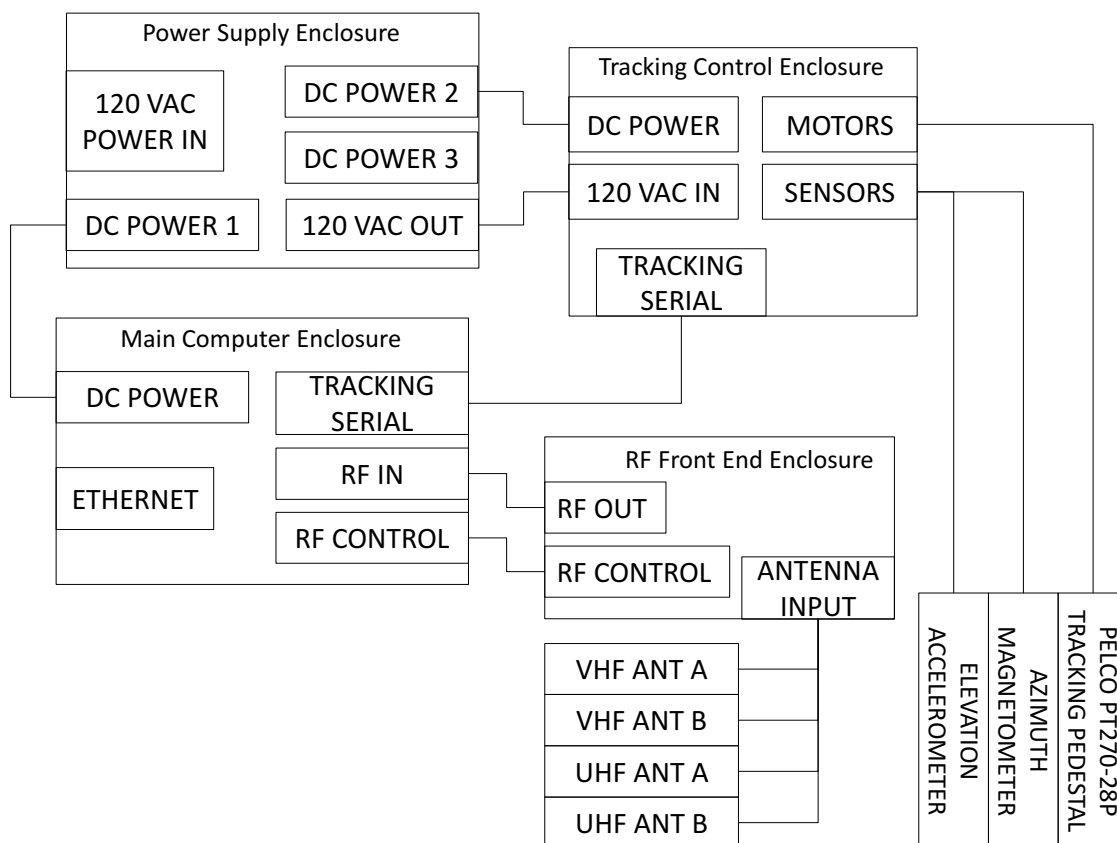


Figure 2: Subsystem Interconnection

4.1 Main Computer and Radio Subsystem

The Main Computer Enclosure contains the BeagleBone Black embedded computer, the FunCube Dongle Pro Plus SDR Receiver, and the RF Control Microcontroller Board. The BBB embedded computer communicates with the RF Microcontroller board and the Tracking Control Microcontroller board (both based on Arduinos) via UART. It also receives NMEA 0183 formatted GPS sentences via UART from a small GPS receiver. This enclosure is powered from the Power Supply Enclosure.

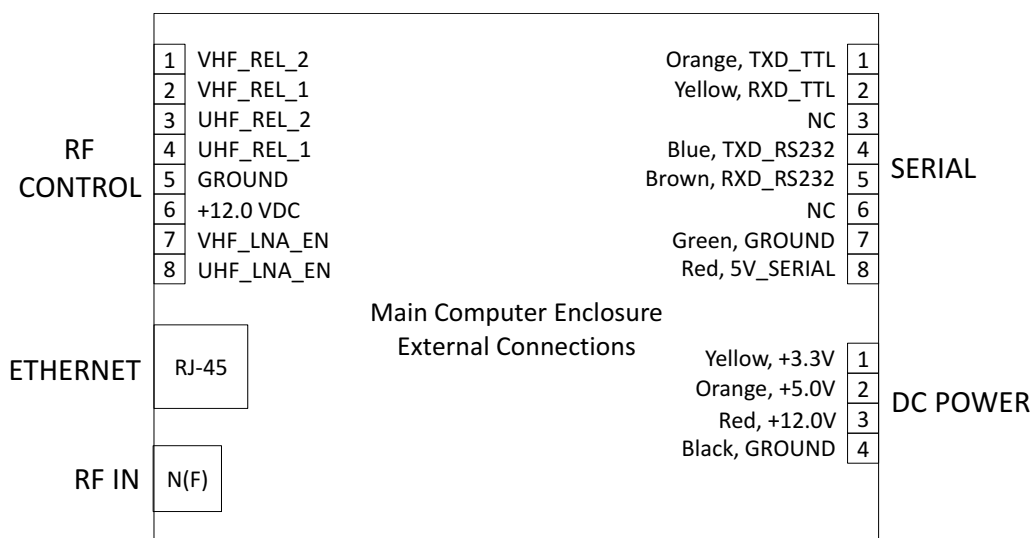


Figure 3: Main Computer Enclosure External Connections

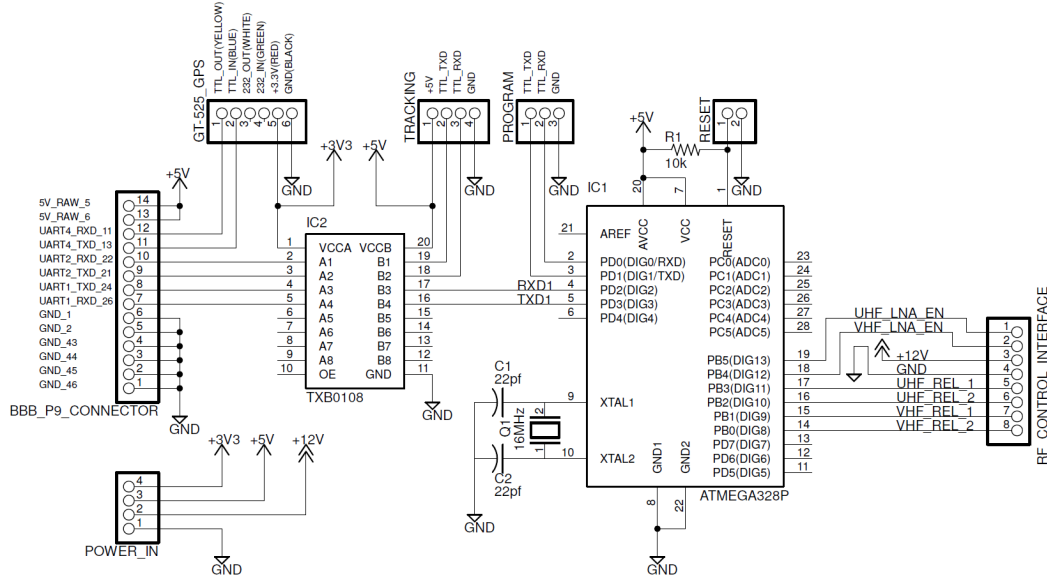


Figure 4: RF Control Microcontroller Schematic

4.2 RF Frontend Subsystem

The RF Front End Enclosure contains the VHF polarization relay, the UHF polarization relay, the appropriate phasing lines for the polarization relays, the VHF Low Noise Amplifier (Advanced Receiver Research's P144VDG), the UHF Low Noise Amplifier (Advanced Receiver Research's P432VDG), the KI0AG 2m/70cm Diplexer, and the RF Control Interface Board. It should be noted that the KI0AG diplexer (also called the "arrow diplexer/duplexer") was fabricated from scratch utilizing information from [8].

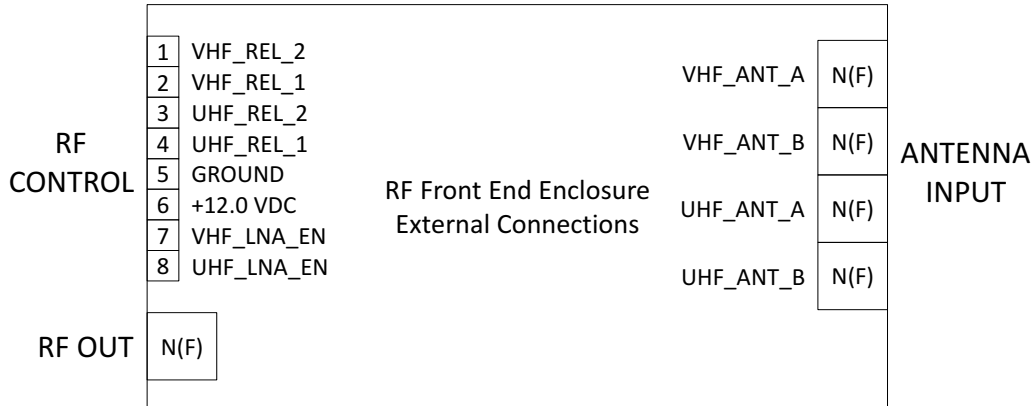


Figure 5: RF Front End Enclosure External Connections

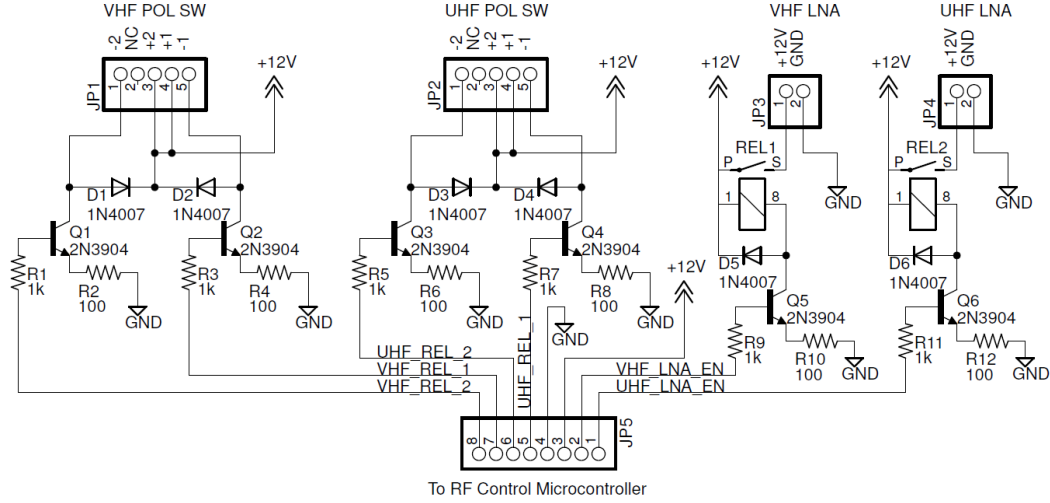


Figure 6: RF Control Interface Schematic

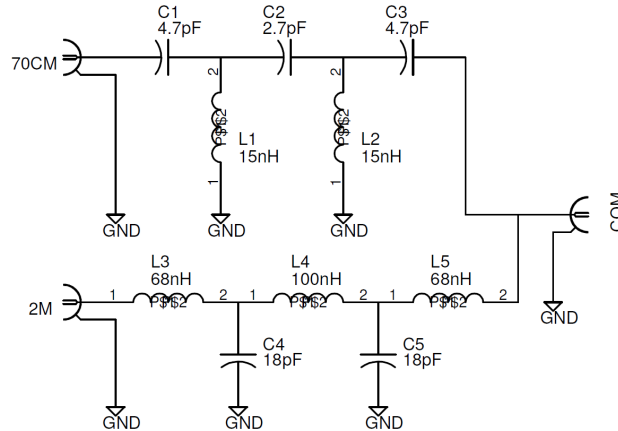


Figure 7: KI0AG Diplexer

4.3 Antenna Subsystem

The antenna subsystem being utilized by the current prototype is a polarization sense selectable system. It is based on a design found in [9]. Figure 8 below shows how two linearly polarized Yagi antennas are connected, along with the appropriate phasing lines, impedance transformers, and a coaxial relay to produce circularly polarized radiation patterns. The polarization sense can be switched by changing the position of the coaxial relay. The current 2m antennas are four element Yagis from Arrow Antennas. The current 70cm antennas are 9 element home-made Yagis. They are oriented such that the pair from a respective band

are at 90 degrees to each other along the long axis of the antennas with the two 2m antennas on the outer edge of the crossboom and the 70cm antennas towards the center (see [9] for a detailed description of the antenna configuration).

Also include in the antenna subsystem is the Pelco PT270-28P Tracking Pedestal and the position feedback sensors. The feedback sensors utilize the I²C protocol to communicate with the tracking control microcontroller board. For azimuth feedback the HMC5883L Triple Axis Magnetometer is utilized. For elevation feedback the MMA8452Q Triple Axis Accelerometer is utilized. Both feedback sensors were obtained from Sparkfun <www.sparkfun.com>.

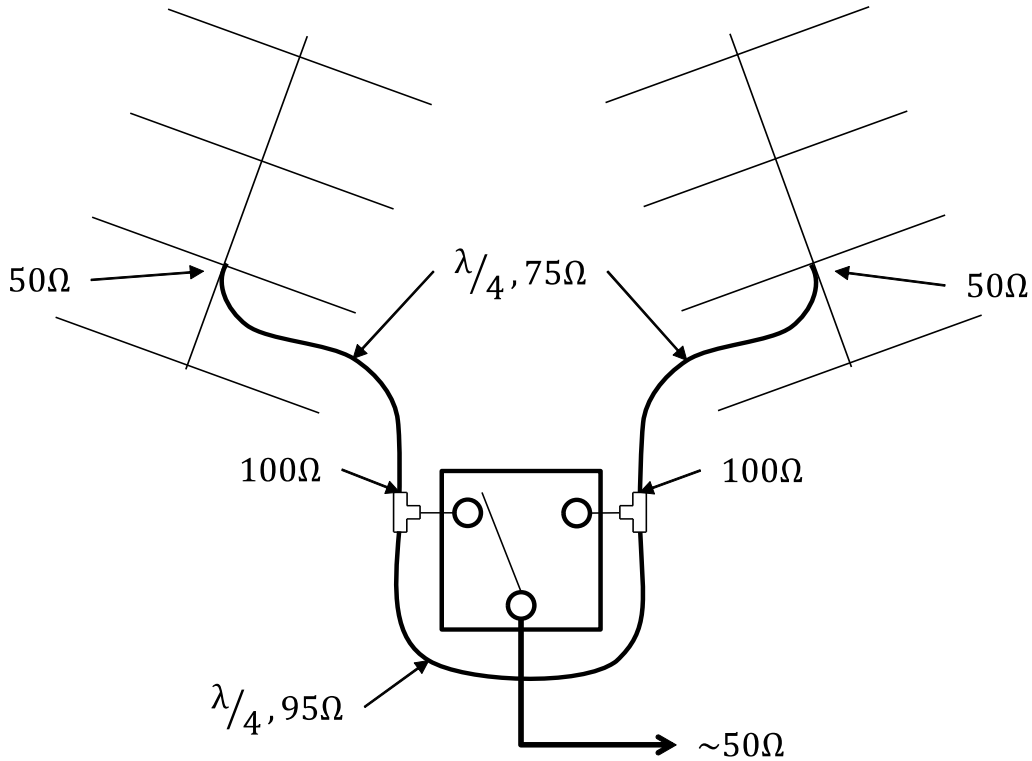


Figure 8: Antenna Circular Polarization Sense Control and Impedance Matching

4.4 Tracking Control Subsystem

The Tracking Control Enclosure contains the Solid State Relay Bank Board, the Tracking Control Microcontroller Board, the azimuth 120VAC to 28VAC transformer, the elevation 120VAC to 28VAC transformer. It interfaces with the Pelco PT270-28P tracking pedestal, the magnetometer azimuth sensor (via I²C), the accelerometer elevation sensor (via I²C), and the Main Computer Enclosure (via UART). It is powered from the Power Supply Enclosure.



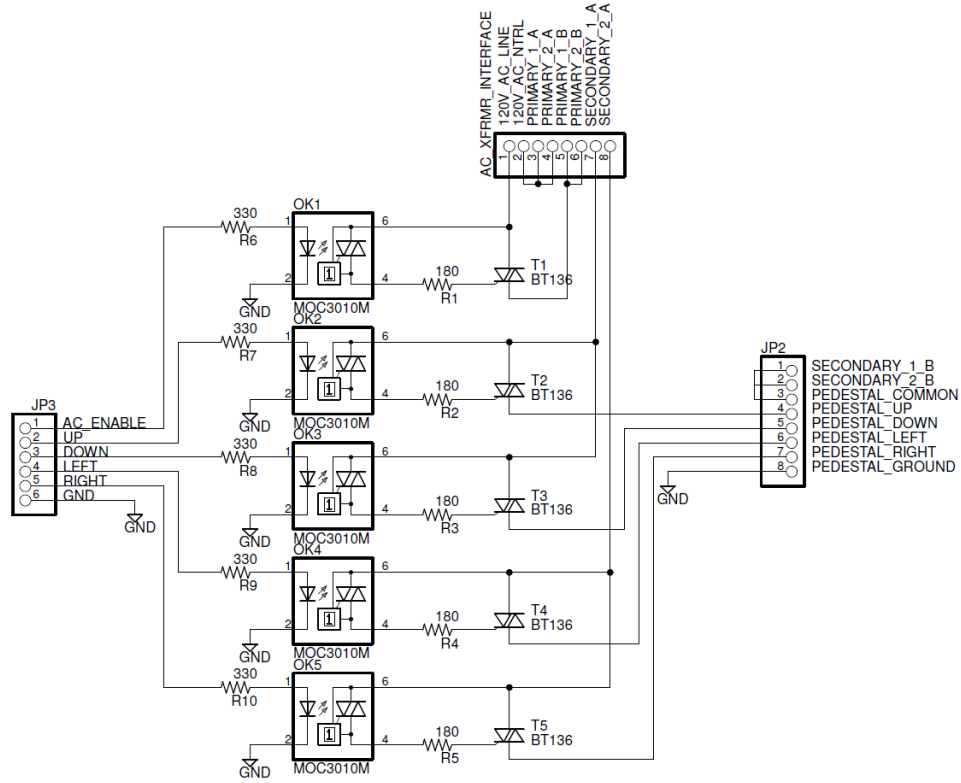


Figure 11: Solid State Relay Bank, Pelco PT270-28P Tracking Pedestal Interface

4.5 Power Supply Subsystem

The Power Supply Enclosure contains three individual Linear DC power supplies, one for +3.3V, one for +5.0V, and one for +12.0V. It also contains individual AC fusing for each power supply as well as the external 120VAC power sent to the tracking control enclosure.

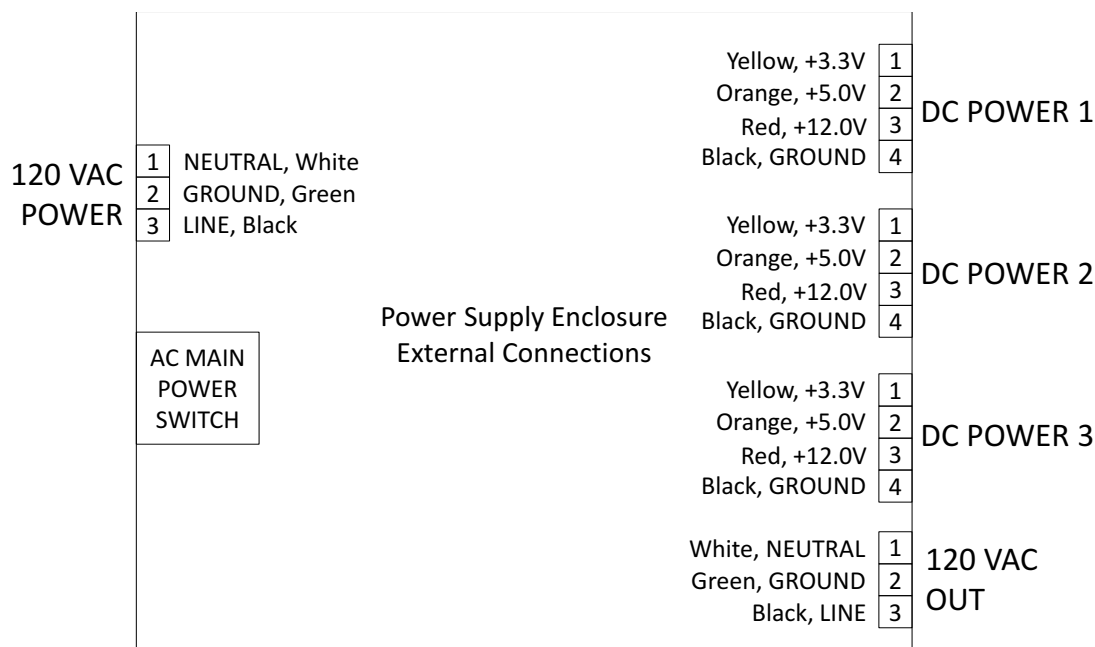


Figure 12: Power Supply Enclosure External Connections

5 Conclusions

This paper calls for a change in the three trends that limit the amount of science data generated that can be successfully transferred from Low Earth Orbit to the ground. The first is the trend to build one ground station per cubesat placed in orbit. When University XYZ builds a new cubesat they usually also (at the last minute) build a control station for sending commands and receiving the mission data. That is it, one cubesat and one ground station. This means the amount of time available to download the increased data generated by the spacecraft is limited to the amount of time the university's control station has line of site with their cubesat, which, depending on the spacecraft orbit, is usually limited to a few passes per day with on the order of ten minutes per pass.

The next trend that needs to change is the use of existing Amateur Radio communications protocols, such as AFSK1200 and FSK9600, to more bandwidth efficient modulation schemes, such as Phase Shift Keying. The utilization of modulation schemes that carry traffic by modulation of the frequency of a signal (such as FM and FSK) are not the most bandwidth efficient method of communicating. If instead the phase of the signal is modulated, for a given amount of bandwidth, the throughput of the link can be increased.

Finally, the almost total absence of Forward Error Correction (FEC) needs to change as well. As always, there are notable exceptions to this (generally from AMSAT), but in

general cubesats do not make use of FEC in their communications links. This can result in loss of data, requiring repeat transmissions, and lowering the overall throughput of a given link.

The correct combination of more ground stations for a given cubesat, the use of bandwidth efficient modulation schemes, and the application of Forward Error Correction in cubesat communications protocols will ultimately result in an increase in the amount of data that can be transferred from the spacecraft to the ground. This can be accomplished all while occupying relatively limited RF Spectrum. The design presented in this paper is a first step towards the goal of realizing a distributed ground station network of SDR-based receiver nodes that will ultimately change the way cubesats communicate.

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W5PFG / P: Observations from a roving operator

How it all began: what sparked my interest?

Back in the spring of 2011, a ham friend of mine, Pete/N1EZT, was visiting from Massachusetts. When I lived in New England from 1998-2006, Pete and I were both active in the Sturdy Memorial Hospital Amateur Radio Club, W1SMH. Each year the W1SMH club would participate in ARRL Field Day and making the 100 point satellite bonus. Usually this was my only satellite activity of the year. During Pete's visit to Texas, we dug out my old Arrow that hadn't seen the light of day since I moved from 1-land in 2006. Neither of us had been very satellite active for several years. Even when I had been on the birds previously, it was on AO-27 or RS-12.

After digging out the old Arrow, Pete and I needed to determine what satellites were active. We found that AO-27 was still around, along with SO-67, AO-51, SO-50, VO-52, FO-29, and AO-7. Wow! It was nice to see a healthy fleet of birds. The very first attempt Pete and I made to utilize the trusty old Arrow was on SO-67. While I transmitted from a 2m mobile on my office on a ground plane antenna, Pete was standing by the window of my living room with an HT listening on 70cm and pointing the UHF side of the Arrow towards the low-elevation pass of SO-67. Pete gave me the "all clear" that nothing was heard on the bird, so I gave my call sign phonetically. Eureka! Pete could hear my voice coming back through the 70cm downlink. To his surprise, a station came back and gave me a call! It was interesting to make the contact using two radios in two separate rooms of the house. It reminded me of the first telephone conversation "*Mr. Watson, come here.*"

The next day, we chose a couple of passes to try, beginning my foray back into the world of amateur radio satellites. I must made at least twenty exciting contacts that first day. I felt like a new ham again!



My daughter Aubrie, learning to steer the Arrow in Spring 2011

First time around: FT-50R & Arrow on AO-27

For a moment, let's flash back to when I operated satellites in Massachusetts, it was mostly using an FT-50R and the original Arrow antenna I purchased at Dayton in the late 90's. I would operate a couple of passes on AO-27 a week, mostly during the day when most people were at work. I really wasn't "addicted" to working the birds at this time. It was somewhat of a novelty to me. The bug hadn't bit yet. Unfortunately I didn't log any contacts back then and I was in a bad habit of not QSL'ing.

Renewed interest: TM-D700 & Arrow on FM birds

Now that I had proven the Arrow was working and my Keps were in proper order, it was time to start making contacts again. Realizing we had four working FM transponders, it made sense for me to utilize one of my favorite portable radios for full-duplex: the Kenwood TM-D700A. This was my go-to portable radio. With the TM-D700A, I was able to set the transmit frequency on one VFO and then tune for Doppler correction on the second VFO. All of the birds at this time were mode J with 70cm downlinks. To utilize the Arrow and the TM-D700A, I had to utilize an external diplexer to split UHF and VHF from the single SO-239 on the back of the transceiver. De-sense did not seem to be a problem so long as I was properly pointing the Arrow at the bird and I did not run more than the minimal power necessary. Low power on the radio was approximately 5 watts. For several months, I utilized this configuration to make literally hundreds of backyard contacts.



Using the Arrow to make contacts on SO-50

Grid chasing: why?

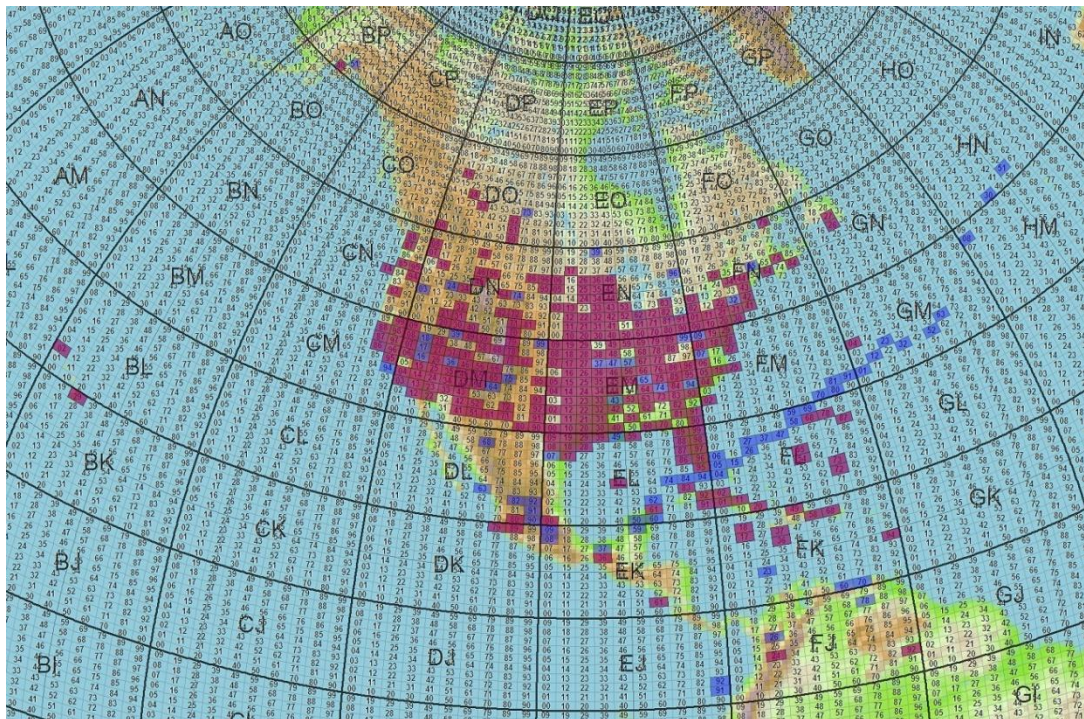
Not long into my foray of working every available FM satellite pass, I started receiving QSL cards. Never in my twenty years of ham radio had I had much interest in QSL'ing. However, something about satellite operation was different. More people sent unsolicited QSL's asking for confirmation of my home grid square, EM21hs. I began to realize they wanted my grid for awards purposes. After this realization, I checked my log and discovered I'd already amassed 50 worked grids in just a few short weeks.

Now the bug was starting to bite. Not only did I live in a grid people wanted confirmed, I was starting to fill my log with new places via satellite. It was time for me to "get in the game." I ordered my first box of QSL cards, 250, thinking it would be enough for a while. Along with the cards, I bought a few roll of stamps and a couple of boxes of envelopes. Little did I know this journey was just about to begin.

Chasing grids provides an opportunity to set goals and attain them over time as you operate. You can watch your grid square map change color as you confirm working stations in new grids. Numerous awards can be obtained such as AMSAT and ARRL VUCC awards. You don't need to work every pass to catch new grids. A lot of times, new grids are on mostly during weekends and holiday periods when operators are traveling.

One of the reasons that I find grid chasing satisfying is it leads to increasing your operating skill. You learn to listen more. Hearing that weak signal as the bird comes over the horizon is your best chance to work a station on the edge of your mutual footprint. On the FM satellites, there is often so much QRM that a weak portable station needs someone listening for only a snippet of his rare grid just to make contact. As someone chasing grids, you are working to maximize your station at all times. You want to hear the bird in all situations – even mobile. This led to my development of a practical mobile satellite station. I needed to be able to work new grids even if I was away from my home.

Below you can see some of the North American grids I've contacted:



Let the roving begin!

As I began to develop my mobile station, I realized that I too could contribute to grid chasers' enjoyment. In my line of work (sales,) I am often traveling by car throughout my state and some adjacent ones. Over the course of a year, I am often visiting 30-40 grids in my region. I've now operated and confirmed contacts FROM over 65 grids since the spring of 2011. Often I will try to work multiple passes from the same grid to allow as many stations to work me as possible. It's often that I will work from a grid-line. There are some generally accepted rules about grid line operations and how they must be validated. I find it quite simple to do using a modern GPS unit. Most of my GPS units are capable of even displaying the current maidenhead grid locator. Smartphones work, too, for this since many include a built-in GPS and grid-locator apps are available.



Since I mentioned QSL'ing being a big part of grid-chasing, I will make a few quick points:

- I've seen great return rates from satellite operators. Usually if someone needs your grid or they are a new station, you can expect full two-way QSL via mail in under ten days.
- Many satellite stations are beginning to utilize ARRL's Logbook of the World.
- QSL'ing for grids can get costly. After I exhausted my initial 250 QSL cards, I ordered another 500. It didn't take long for those to disappear. My next order was 1000.
- For each QSL you truly desire returned, include a SASE. This is not a lot different than any other mode or aspect of ham radio.
- Always include your grid and the grid of the station worked on each card. It is important to denote if you were roving or mobile outside your home grid.

One of the joys of chasing grids is when you work one of many active roving and portable operators. These are people who travel to grid squares and operate satellite passes from them, often for the first time in many years. I have been fortunate to confirm many grids for people who have been waiting on a confirmation for a decade or more. Some of the rarer ones I have visited are out in West Texas, DM80-86. Bear in mind that even if hams live in a grid, and it's a highly populated grid, there may not be many active satellite operators.

There are too many active rover stations to name them all, but I will highlight a few:

- Yuri/UT1FG: If you do not know who Yuri is, you probably do not care about chasing grids. Yuri is a Ukrainian ship captain. While he is at sea around the globe, you can work him via the birds. He is an excellent operator who has confirmed grids for countless operators worldwide. Personally he has confirmed well over 100 grids for me while others have worked him in two or three times that many. Yuri has an excellent QSL manager and his return rate is 100% when proper techniques are used.
- Jim/ND9M: Jim is not only active on satellites, he runs counties as well. The fun thing about working Jim is that he might be on land OR at sea. As a Radio Electronics Officer onboard a ship, you are likely to work him when in a mutual footprint. In his time on land, Jim has been found roving grids all over the USA.
- Patrick/WD9EWK: Many active operators have had the privilege of working Patrick as he volunteers for AMSAT at many hamfests in the southwest USA. Patrick is always friendly and one of the fastest to QSL I've ever encountered. I don't know how he manages to do it, but my Logbook of the World contacts with him confirm almost as soon as I upload my contact details.

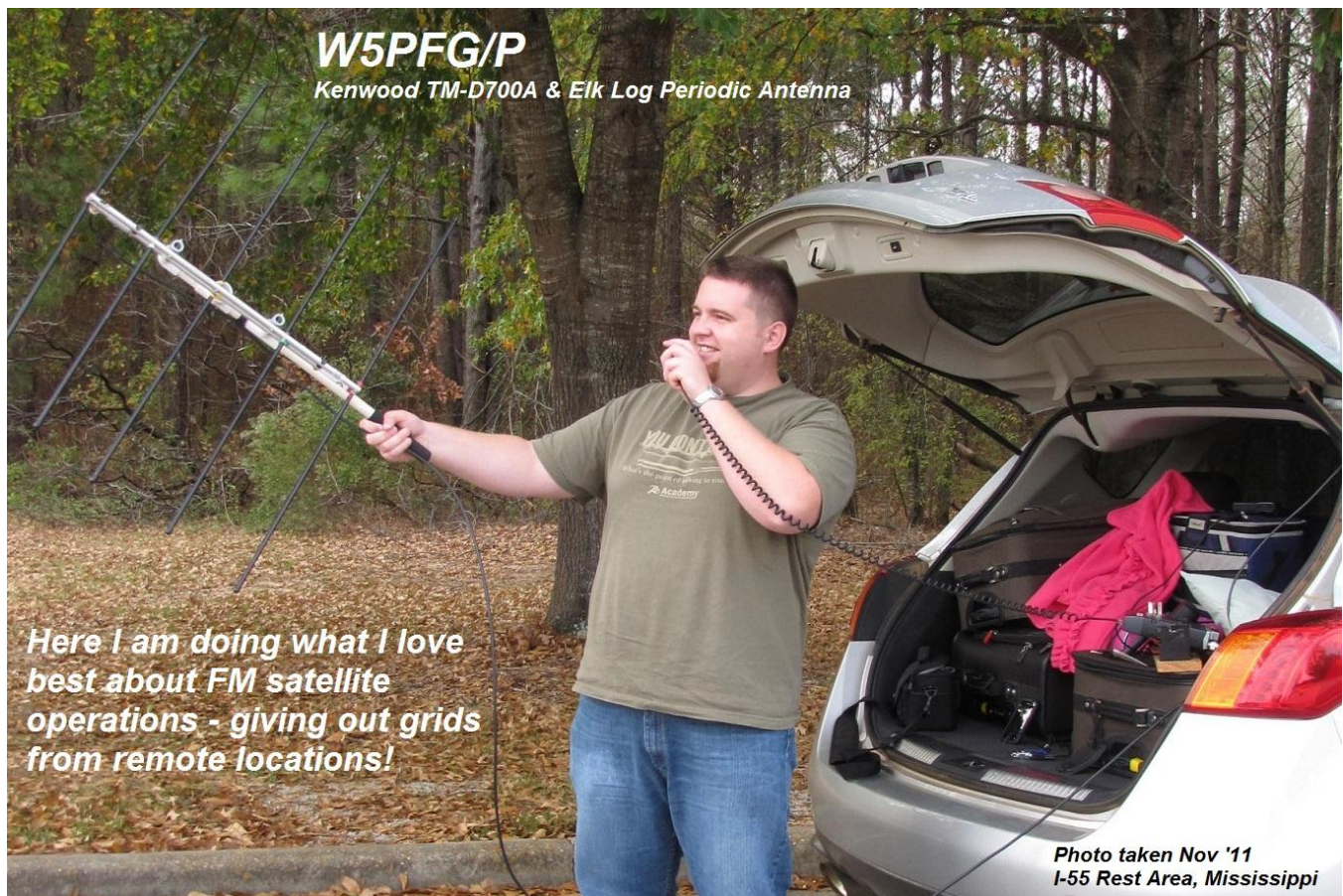
Roving is not for everyone. I've encountered local and federal law enforcement, curious folks stopping to ask me questions, and severe weather throughout some of my operating experiences.



Current gear options: what works?

There are a wide range of options to consider when building a satellite station. For this discussion, I will focus on mobile and rover operating, my latest passion in amateur satellites. Since becoming a ham, I have seen the cost of transceivers decline significantly, especially multi-mode VHF/UHF gear. With many manufacturers offering HF/VHF/UHF all-in-one transceivers, satellite operators have many options for both uplink and downlink use.

Ideally, your station should be compact if operating from a vehicle. This would generally rule out large base rigs unless you have room. Unless you are dedicating the vehicle to rover use, you probably can't afford the space of my favorite rig, the Icom IC-910H.



I used this image above to send out some special rover QSL's.

Some transceivers that I have found worked well in my mobile station:

- Yaesu FT-100D: This was my first VHF/UHF all-mode radio in the car. It allowed me to work FO-29, VO-52, and AO-7 all half-duplex. It was not long before I realized I needed to add a receiver.
- Kenwood TM-D710A: I added this radio for full-duplex FM satellite capability. Unfortunately the current satellite situation on FM limits us to SO-50 only. I've since retired this radio to the shack.
- Yaesu FT-857D: I purchased an FT-857D for the car so that I could use CAT control if I so desired. I do almost all Doppler correct manually, but I can use a laptop for Doppler in a pinch.
- Yaesu FT-817: Probably my best purchase, this radio serves as my receiver for most satellite operations in the car. With it and a decent antenna, I can receive AO-7 down to the horizon from a good operating location. I also use the FT-817 for a very lightweight, portable, all mode satellite station.

Antennas while operating from a vehicle can make for some interesting conversation online. Over time, I tried many different configurations. My favorite, for operating mode J, is to utilize a vertical for the 2m uplink and then use my Arrow UHF antenna for the 70cm downlink. Mode B is a little more difficult. I often use a second antenna, a 19" whip, on the roof of my car along with a preamp to receive the 2m downlink. Other times, I will set a 2m Arrow outside the car on a tripod and manually turn it from the driver's side window. In my car I normally carry several feed lines and several antenna options. This includes a spare Arrow, an Elk, a CJU, and even an extra 19" whip.



Operating from a remote grid in West Texas on vacation in Spring 2013.

From my mobile operating experience, I have learned a few things that really help make the station perform well. These same things apply well to a fixed home station:

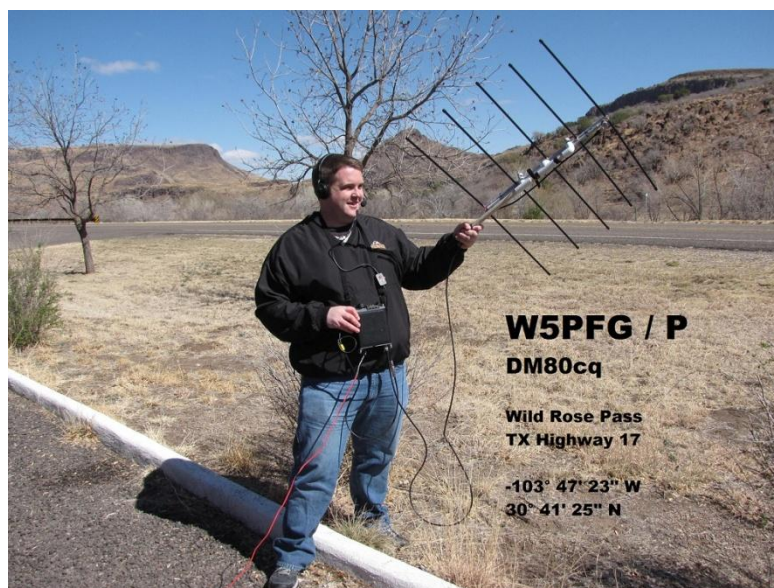
- Full-duplex capability: If you can't hear yourself, you are likely causing QRM or not making it into the bird at all. I am a stickler for this. Inexperienced operators "guessing" their ability to fully capture the bird cause a lot of QRM daily on the FM satellites. This is not a must, but highly recommended.
- Feed lines: As many know, satellite work is like weak signal operating. Using RG-58 is just not going to work very well, even at short distances in the portable environments. Believe it or not, you can tell a significant different in using poor quality feed lines versus quality feed lines. I often use LMR-240 or LMR-240uf for my portable jumpers.
- Receive preamplifiers: A preamp is an indispensable tool for the mobile operator. It allows you a little forgiveness for not pointing the antenna you're using directly at the satellite. There is one downside, however, and that is if you're operating in a very noisy RF environment. I call my preamps "cheaters" because it feels like I'm cheating when I use them on the road. They make that big of a difference!

General mobile operating observations

The time and day of week can really make a difference on the number of contacts you'll make. If you intend to only operate late night or early-morning passes, it is unlikely many people will work you. It's best that you announce your mobile operations via AMSAT-BB or other means.

Terrain matters. When you're mobile, you often can't be picky about where you park your car to operate. I have found my favorite operating location to be the high plains of West Texas. Out there, at 3,600' elevation, you can see to the horizon in almost all directions. Operating in my native East Texas poses a couple of challenges, namely trees and rolling hills with varying +/- 100' in elevation changes.

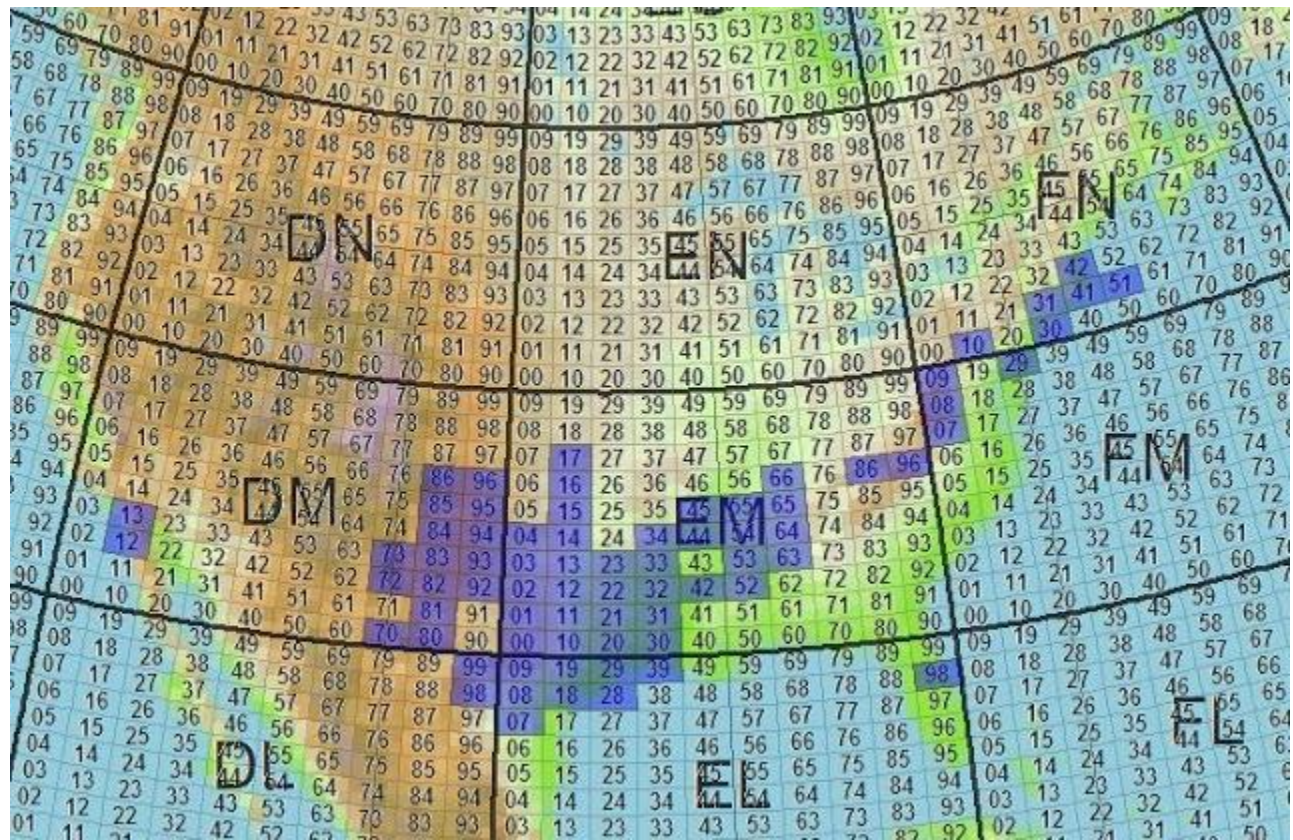
Local noise can be a huge factor when you pull over your vehicle to work a satellite pass. I have occasionally pulled over to work a satellite pass only to discover a noisy transformer interrupting my reception of VO-52 or AO-7. There's not much you can do to avoid this situation other than try to select an operating site in advance of the pass you desire to work, giving yourself time to move if the original site is unsatisfactory.



Future of operating amateur satellites mobile

If there are no more satellites carrying transponders, no one is making contacts. At the time I got bitten by the bug, there were seven available voice transponders. We're now down to four at the time of this article. Fortunately there is a series of launches in late 2013 going into 2014 that will carry satellites with amateur transponders.

I strongly recommend that operators who enjoy satellites get on board with your local AMSAT organization and consider supporting foreign AMSAT entities with clearly stated missions. AMSAT-NA, AMSAT-UK, and other groups have satellite projects in the works. Those birds will not make it into orbit without your financial support. Without satellites, general operator interest dwindles, and as a result the special interest organizations often see a decline in membership.



North American grids from which W5PFG, the author, has operated from via satellite.

Operating on Satellites from Cruise Ships – Lessons Learned on Nine Cruises

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Abstract

Operating on satellites from a cruise ship is something many satellite operators have wanted to do; however, it is necessary to obtain both permission to operate amateur radio on the ship and the proper amateur radio license. There could be serious consequences for someone who operates amateur radio on a ship without fulfilling these requirements. Advance planning and preparation are needed to both fulfill these requirements and to select and become familiar with the radio equipment to be used.

Requirements for Maritime Amateur Radio Operation

The two primary requirements for operating amateur radio while on a ship are obtaining permission to operate and proper amateur radio licensing.

Part 97 of the rules of the Federal Communications Commission is quite clear:

“97.11 Stations aboard ships or aircraft

(a) The installation and operation of an amateur station on a ship or aircraft **must be approved by the master of the ship** or pilot in command of the aircraft.

(b) The station must be separate from and independent of all other radio apparatus installed on the ship or aircraft, except a common antenna may be shared with a voluntary ship radio installation. The station's transmissions must not cause interference to any other apparatus installed on the ship or aircraft.”

In addition, the information available on the ARRL website regarding maritime operation by US amateur radio operators (<http://www.arrl.org/maritime-mobile-operation-in-international-waters>) states “When an FCC licensed amateur is operating an amateur rig aboard a US-registered vessel in international waters, he or she must follow Part 97 of the FCC rules, particularly Section 97.11.... If the ship is of foreign registry, (he or she) must obtain a reciprocal operating authorization for the country of registry in addition to being in compliance with Section 97.11.”

Again, the two primary requirements for operating amateur radio while on a ship are obtaining permission to operate and proper amateur radio licensing.

Obtaining Permission to Operate

Some cruise lines have had bad experience with amateur radio operators in the past, and as a result, they may not allow amateur radio operation on their ships. There are documented cases of ham radio operators putting up vertical or wire antennas on ships and operating without permission. Due to safety considerations, cruise ships will not allow antennas to be attached to the ship, and runs of coaxial cable are also considered to be a safety hazard. A small number of

cruises organized by groups such as the Quarter Century Wireless Association (QCWA) have put together ham radio cruises with HF operation permitted but individual operators have little to no chance of obtaining permission to operate on HF with large antennas. Fortunately, the UHF/VHF bands employed by satellites lend themselves to the use of handheld equipment.

In 1999 the international regulation requiring all ships at sea to monitor the international CW distress frequency of 500 kHz was dropped and many cruise lines no longer have radio officers. Instead, they have communications officers whose responsibility includes maintaining both the information technology (IT) network and the radio systems on board the ship. The communications officers on many ships are very computer oriented and know little about radio communications.

With the tighter security imposed because of the increase of terrorism in the world, it is often no longer possible to speak with the communications officer. It used to be possible to meet with the radio officer on a cruise ship (MacAllister, 1997), and this often made it easier to obtain permission to operate. I have been successful submitting written requests to operate amateur radio on ships.

My written requests to operate amateur radio on a cruise ship are submitted to the purser's desk for forwarding to the communications officer. It is better to write a letter requesting permission to operate before leaving home, and to print out several copies to take along on the cruise. A neat legible typed letter that has been carefully worded has a better chance of obtaining approval to operate than a letter written by hand while standing at the purser's desk with little advance thought given to the wording.

The primary concern when deciding whether or not to allow amateur radio operation on board a ship is that of safety and preventing possible interference to any apparatus or systems installed on the ship. We all know that operation of radio transmitters sometimes causes RFI, and that is why some cruise lines forbid passengers to operate any kind of two-way radio on board their ships. Fortunately, the UHF/VHF bands employed by satellites lend themselves to the use of low power and handheld antennas, and seldom result in RFI.

Because many of today's communication officers do not have the in depth knowledge of radio theory possessed by the radio officers of the past, when requesting permission to operate it is necessary to address any negative perceptions regarding amateur radio that they may have in their mind. It is important that several points be clearly made in the written request to operate. The letter I have developed after several cruises requests permission to operate a small low-power handheld amateur radio on board during the cruise. I state that the radio is very similar to the Family Radio Service (FRS) radios used by many passengers, but operates on the 145 MHz VHF and 435 MHz UHF amateur radio bands. I tell them that I typically operate for very short periods of time, usually 10 to 15 minutes three or four times a day. I do not tell them that I will operate through a satellite or give them any details they do not need to know. The cruise line does not want any passenger to do anything that will disturb other passengers, so I state that I use a small headset with a microphone when I operate the radio so that I do not disturb other people. I usually end my letter by stating that I have operated this equipment on cruises in the past and

that it did not cause any problems. If it is a cruise line I have sailed on in the past I name the ships that I have operated on. Cruise lines like passengers that return on future cruises.

The time it takes to receive a response after a request to operate amateur radio has been submitted varies with both the cruise line and the ship. On one cruise with Princess Cruises, written approval to operate amateur radio was delivered to my stateroom eight hours after I submitted my request at the purser's desk. On a later cruise with Princess I turned in my written request at 5 PM and received a telephone call from the communications officer at 7 AM the next morning giving me verbal approval to operate. Princess Cruises is one of the more amateur radio friendly cruise lines. Other amateur radio operators have reported having a good experience operating from ships of the Holland America Line and the Norwegian Cruise Line.

Some amateur radio operators who sailed on Carnival Cruise Lines have reported that they did not receive a reply to their written requests to operate amateur radio while on the ship. What most amateur radio operators do in this situation is to assume that if after reading the request the communications officer hasn't notified them that it is not permitted, they are allowed to do it. I experienced a similar situation on a cruise with Royal Caribbean International. My written request was returned to my stateroom the next day by ship's mail with no comments or markings on it. Since the communications officer knew I wanted to operate amateur radio and he didn't notify me that I couldn't operate, I assumed it was permitted.

The Celebrity Cruise line reportedly has a policy of not allowing passengers to operate any kind of two-way radio on their ships. Even though the promotional material that Celebrity sends to passengers and prospective passengers does not mention the policy, my travel agent was told by a Celebrity agent that they would confiscate any amateur radio equipment they found on board one of their ships.

Sometimes approval is given to operate amateur radio on a cruise ship, but with restrictions. For example, one radio officer approved my request to operate, but not at a full power of five watts. He was concerned about possible interference to the ship's radios on the 156 MHz VHF marine band. During that cruise I was careful not to transmit near any antenna on the ship that looked like it was used for VHF. Now that future satellites will be using UHF uplinks we should also avoid transmitting near any UHF antennas.

In some instances, radio amateurs are asked not to transmit during critical periods such as when the ship is entering or leaving a harbor, or docking (MacAllister, 2000). On one cruise, I chose not to transmit while passing through the Panama Canal. There were so many different simultaneous radio transmissions that I heard almost constant intermod on my HT. If I had transmitted at that time it is likely that I would have contributed to the intermod and been heard by other radio operators along the canal and on the ship. It is very important that amateur radio operators on board ships be careful not to do anything that may result in the denial of future requests by amateur radio operators for permission to operate on the ship.

In some ways, obtaining permission to operate is probably the single largest obstacle facing those who wish to operate amateur radio on cruise ships. There is always the possibility that once you have obtained the necessary licensing and boarded the ship you will not be able to operate.

Licensing on Foreign Flagged Vessels

The basic rule regarding licensing for amateur radio on a ship is that operation in international waters requires the operator to have an amateur radio license from the country in which the vessel is flagged. If the vessel is not in international waters, but in the territorial waters of a nation, it is necessary to have an amateur radio license from that nation in order to operate amateur radio from the ship. Fortunately, a number of international treaties and conventions make foreign licensing relatively easy for US amateur radio operators. The American Radio Relay League (ARRL) web page (<http://www.arrl.org/international-operating>) has a great deal of information on these international agreements, as well as on reciprocal licensing (Mattis, 2003 & 2005).

European Conference of Postal and Telecommunications Administration (CEPT)

The European Conference of Postal and Telecommunications Administration (CEPT) agreement T/R 61-01 gives US radio amateurs operating privileges in most European nations. All that is necessary is to have in your possession proof of US citizenship, your original FCC amateur radio license (Technician class or higher) and a copy of the FCC public notice entitled “Amateur Service Operation in CEPT Countries” (DA 11-221, dated February 7, 2011) which is available on the ARRL web page. I have used CEPT operating privileges to operate on ships flagged in the United Kingdom and Norway, and to operate onshore in Curacao, St. Bartholomew, Italy, France, Spain, Portugal, Azores, and Denmark.

International Amateur Radio Permit (IARP)

The Inter-American Telecommunication Commission (CITEL) has adopted an agreement for an International Amateur Radio Permit (IARP) that is valid in eleven countries in North and South America. The participating countries are Argentina, Brazil, Canada, El Salvador, Panama, Peru, Trinidad and Tobago, United States of America, Uruguay, and Venezuela. The IARP is issued to US amateur radio operators by the ARRL and detailed information including an application form is available on the ARRL website (<http://www.arrl.org/files/file/Regulatory/iarp-app.pdf>). It is necessary to provide a passport photo and a copy of your FCC license (Technician class or higher) when applying for an IARP. The processing fee for an IARP is \$10 and it is valid for one year. I have received reports in the past year that processing at ARRL headquarters may take several months. I have used an IARP to operate from Panama and Venezuela.

Reciprocal Licensing

In addition to CEPT and IARP, the United States has a large number of reciprocal agreements with other nations regarding amateur radio. These agreements make it possible for FCC licensed radio amateurs to obtain a foreign amateur radio license without having to take an examination. In the course of my nine cruises I have operated from 21 different ARRL DXCC entities. Reciprocal licenses have made it possible for me to operate while the ships were docked in foreign ports or while I was onshore in ports of call. In some nations such as the Bahamas, Bermuda and the British Virgin Islands reciprocal operators use their home call sign appended with the amateur radio prefix for the reciprocal country (for example, N5AFV/C6A,

N5AFV/VP9 and VP2V/N5AFV). Some of the reciprocal licenses I have received issued a foreign call sign to me such as Dominica (V79AFM), Cayman Islands (ZF2FA) and Belize (V31FV).

One downside of reciprocal licensing is that most of the permits cost \$20 or \$25 a year, and sometimes personnel checks or cash are not accepted for payment. US Postal Service money orders are accepted in most, but not all, nations. The Cayman Islands is an example of a nation that does not accept US Postal Service money orders; however, the Cayman Islands will accept a cashier's check from a US bank.

Another drawback to reciprocal licensing is that some nations take a long time to process an application. My application for a reciprocal permit in Belize took six months to process, and I did not receive it in time to use on my first visit there. It has been my experience that most countries take at least six weeks to process an application. Those who are planning to operate on a cruise should begin their application procedure at least three months in advance, and as I found out with my application to Belize, it sometimes takes even longer.

Many ships are flagged in Bermuda, and a four-month reciprocal license is available from Bermuda by mail at no cost. Information is available on the Radio Society of Bermuda website (<http://www.bermudashorts.bm/rsb/visitors.htm>). Most of my cruises have been with Princess Cruises whose ships are flagged in Bermuda.

The ARRL web page does a good job of providing information on reciprocal licensing; however, the information that is posted on the ARRL web page is not always up to date. For example, the name of the agency that issues amateur radio licenses and permits in the Cayman Islands had changed since the information was posted on the ARRL web page, and the cashier's check I sent with my application was returned with a request for a check made out in the new name of the agency. Also, my application for a reciprocal permit in Jamaica was returned to me six weeks after I mailed it with notations on envelope stating "No such box number" and "Returned for better address." There was not enough time left before my cruise to re-apply for a reciprocal license in Jamaica, even if I could find the correct address. One possible solution to out of date information is to attempt to verify the information on the ARRL web page by either contacting the licensing agency in the foreign country if an e-mail address is given, or by contacting another amateur radio operator who has recently operated from that country. Verifying the information on the web page takes additional time, and I found out that the three months I had allowed for obtaining licenses in Jamaica and Belize was too short.

Finally, there are some DXCC entities visited by cruise ships where you can operate with a US amateur radio license. Examples are Puerto Rico, US Virgin Islands, Alaska and Hawaii. US operators also have instant operating privileges in Canada. However, cruise ships seldom spend more than six to eight hours in a port, and most radio amateurs who operate on a cruise do the majority of their operating while the ship is underway and spend the time in port seeing the sights and enjoying the things that tourists do.

The Operating Environment on a Cruise Ship

When most people think about operating amateur radio on a cruise ship, they visualize someone sitting in a comfortable deck chair in the warm sun sipping a cool drink between or even during contacts. Only a small percentage of amateur radio satellite contacts made from a ship resemble that mental image. The fact is that the operating conditions on the open deck of a ship at sea are often hostile in nature. First of all, there is usually a strong wind. If the ship is moving at approximately twenty knots into a twenty five knot wind there will be a fifty mile per hour wind blowing across the deck. Use of a headset allows me to hear my radio under such conditions. If you have ten to fifteen foot seas the ship will be rocking significantly. Also, the deck may be wet from ocean spray, and it could even be raining. It may be cold; I have experienced temperatures in the 40-to-45 degree Fahrenheit range on ships in the northern Gulf of Mexico during December and January. As we know, some satellite passes occur in darkness. If all of these conditions happened to occur at the same time, the operating conditions could be extremely hostile, and care must be taken not to fall overboard while operating.

It is important to keep these operating conditions in mind when selecting the equipment to be used for operating the amateur radio satellites on a cruise. The equipment should be light weight, water resistant, and operate on self-contained batteries. I also take the approach that the equipment should not draw undue attention to the operator. If just one other passenger makes a negative comment to the ship's crew about the amateur radio operation, it is possible that the communications officer or captain would shut down the operation. On one of my cruises another passenger watched me operating a satellite pass and asked me what I was doing. I thought it would be a good opportunity to talk up ham radio and AMSAT, so I explained what I was doing. The passenger's first comment after I finished my explanation was to ask about people's right to privacy on the satellite. There was no way he would believe that I had authority to talk over a satellite, and he was convinced that I was illegally listening to telephone calls. If he had reported the incident to the ship's crew my maritime mobile amateur radio operation would possibly have been shut down.

Because I feel that it is important to keep a low profile and not attract attention, I no longer use an Arrow antenna on cruise ships. I used an Arrow antenna on one cruise and learned that an assembled Arrow antenna is too large to carry in congested tight passageways. It is also very time consuming to assemble and disassemble an Arrow antenna before and after each satellite pass. My use of the Arrow antenna on that cruise was restricted to the veranda of my stateroom. On another cruise I packed my Arrow antenna without testing it, and when I assembled it on the ship and tried to work an SO-50 pass I could hear the satellite, but I could not get into the bird. The duplexer in the Arrow handle was defective on the two meter side, and the Pryme AL-800 I had packed as a backup antenna became my primary antenna for the cruise.



Andy MacAllister, W5ACM/C6A, using arrow antenna to make a ship-to-ship satellite contact from the Gulf of Mexico to the Pacific Ocean
(Photograph courtesy of W5ACM)

Other satellite operators such as Lee Devlin, K0LEE, (Anonymous, 2000) and John Sheets, N8QGC, (Sheets, 1999) have used the Arrow antenna on cruises. Andy MacAllister, W5ACM, has also used an Arrow antenna on cruises (MacAllister & Mattis, 2004). Whether or not to use an Arrow antenna is up to the personal choice of the individual operator.

My preferred choice of equipment radio to use on a cruise ship consists of my out-of-production Icom W32A HT with a telescoping Pryme AL-800 antenna. The AL-800 antenna fits in your pocket and only takes a couple of seconds to attach to your HT and be ready for use.



Allen Mattis, VP2V/N5AFV using AL-800 antenna while docked at Tortola, BVI
(Photograph courtesy of N5AFV)

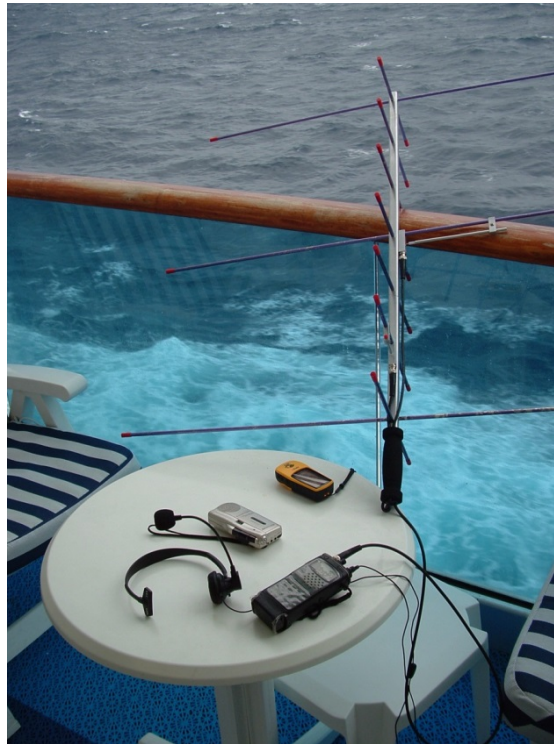
However, the AL-800 is heavy and comes with a BNC connector. Unfortunately, today's mini-HTs have SMA connectors. Adapters from BNC to SMA are available but the SMA connector and small case on a mini-HT may not support the weight of an AL-800. Fortunately there are lighter antennas available. Soifer (1999) has had success using the MFJ-1717 16-inch rubber-coated dual-band antenna for working satellites, and MacAllister (1997) used the similar Diamond RH77 15-inch rubber-coated dual band antenna on his cruise. Both of these antennas originally came with BNC connectors, however, SMA versions are now available. On one cruise, I was able to switch back and forth between the Pryme AL-800 and MFJ-1717 antennas while making contacts on SO-50 and AO-27. I found that both antennas performed acceptably; however, the Pryme AL-800 appeared to provide slightly better reception than the MFJ-1717. I usually take an MFJ-1717 along on my cruises as a backup antenna. Pryme has recently come out with the RD-98 16-inch rubber-coated dual band antenna that has higher gain on UHF than the MFJ-1717 and Diamond RH77, and is available in both BNC and SMA models.

A number of satellite operators have used the Yaesu FT-817 with self-contained batteries for portable operation (Glasbrenner, 2005). Gene Marcus, W3PM, operated on amateur radio satellites from the Queen Elizabeth 2 in the North Atlantic in both 2002 and 2003 using an FT-817 with a home brew 2-element quad for receive and a 19-inch whip for transmit. Whether you plan to use an HT or a larger rig, you should take along extra rechargeable batteries and a battery charger. Staterooms on almost all cruise ships in North America are equipped with 120 volt AC power systems compatible with standard battery charging devices.



Gene Marcus, G/W3PM, operating satellites with a Yaesu FT-817 aboard the Queen Elizabeth 2
(Photograph courtesy of W3PM)

Besides the transceiver and antenna, other equipment is needed to efficiently operate on board a ship. A GPS unit is essential to know the maidenhead grid square in which the ship is located, as well as the direction the ship is moving. It is necessary to know the direction the ship is moving to determine which side of ship to be on in order to work a low elevation satellite pass. I have already mentioned that I use a headset so my radio will not disturb other passengers; an inexpensive MFJ-288I headset has served me well. I have also found that a small, voice-activated tape recorder allows me to record the call signs of the stations I work. In order to keep the set up simple, the recorder does not record from the radio, but records only my voice. After the satellite pass, I transcribe the information on the tape recorder into a hard copy log. Other miscellaneous items to remember to take along include extra batteries for the GPS unit and tape recorder, and the user's manual for your radio. I sometimes take a few pieces of backup equipment along such as a speaker microphone or extra headset, and few basic tools like black electrical tape, screw drivers and pliers.



N5AFV radio equipment spread out on the table of veranda. On more recent cruises the arrow antenna has been replaced by the telescoping Pryme AL-800 antenna
(Photograph courtesy of N5AFV)

Each amateur radio operator on a cruise ship must decide the best way to obtain pass predications for the satellites. I try to travel light on cruises, so I do not take a lap top computer with me. Because I know the itinerary of the cruise ship before I leave home, I am able to print out pass predictions in advance for the entire cruise. Most cruise ships have Internet access available, and on the rare occasions when it appeared that my pass predictions were not correct

or the ship deviated from the scheduled itinerary I was able to go to the Heavens Above web site (<http://www.heavens-above.com/>) and obtain the information I needed.

It may also be desirable to have copies of the receipts showing when and where you purchased your radio and any other expensive pieces of gear. This documentation may be needed if you plan to take these items ashore at a stop or when you go through customs upon return. I generally put together a small three-ring binder containing these items along with a few maps, my amateur radio licenses and permits, the pass predictions, log sheets and any other related items I feel I may need.

It is also a wise plan of action to thoroughly inspect and check out each piece of equipment before you leave. If something needs repair, you will have time to do it or have it done. One way to check out the equipment is to make contacts with it before the cruise. My usual procedure consists of using my W32A HT and AL-800 antenna to make 75 to 100 satellite contacts during the month prior to the cruise. On the final day of practice operation five days before my first cruise I was working a satellite pass and received two reports of low audio. Testing indicated that the microphone in my MFJ-288I headset was not working properly, and I replaced the headset before leaving. Making practice contacts before the cruise also prepares you for operating on the ship. It is easier to make contacts in the dark or under hostile conditions when you are used to using the equipment. Also, it is essential that an amateur radio operator have experience operating on the satellites before attempting a cruise operation, and a “newbie” or new operator can gain that experience in a just few weeks of practice operation.

Summary

Operating on satellites from a cruise ship is relatively easy if advance planning and preparation are done. Obtaining the necessary amateur licenses usually takes at least several months, and a carefully worded written request prepared in advance increases the likelihood of receiving permission to operate. Selection and thorough testing of the equipment to be used should not be left to the last minute. An amateur radio operator attempting to operate on satellites during a cruise should have prior satellite operating experience. If these steps are followed, operating satellites from a cruise ship can be a very rewarding experience. Those who operate on the satellites from a cruise ship soon find out how much fun it is to be called by dozens of amateur radio operators pursuing new grid squares for the ARRL VUCC satellite award.

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OVERCROWDING OF THE TWO METRE SATELLITE BAND

Hans van de Groenendaal, ZS6AKV
IARU Satellite Adviser

The band 144-146 MHz is allocated to the amateur service and the amateur-satellite service world-wide on a primary basis, with exceptions in several footnotes. This most used of all VHF amateur bands, accommodates weak signal terrestrial and moon-bounce operation, packet radios systems including APRS, propagation beacons, repeater systems, and satellite communications. IARU band plans in Regions 1 and 3, along with domestic band plans, help to maximise use and minimise interference.

These plans place the amateur-satellite service in a 200 kHz wide band from 145,800 – 146,000 MHz. Frequency coordination requests received by the IARU Satellite Advisor, including linear transponders and single channel per carrier systems, are so many as to require all users to accept channel sharing and to tolerate interference. To mitigate interference, use of this band is recommended for downlinks only, to minimize interference from non-amateurs (illegals like taxis and cross-town telecom links).

TOO MANY SATELLITES – too few frequencies

CubeSats have developed as a low cost entry into space for experimentation, putting further pressure on the 145,800 – 146,000 MHz satellite band. The combination of low cost amateur and commercial radios along with free IARU frequency coordination, have made this band very attractive to universities and commercial experimenters.

RES757(g) notes that, “currently, many nanosatellites and picosatellites use spectrum allocated to the amateur satellite service ... in the frequency range 30-3000 MHz *although their missions are potentially inconsistent with these services.*

Essentially, RES757 recognizes that many missions appear to be *inconsistent* with definitions of the amateur service and amateur-satellite service – RR1.56 and RR-1.57.

RR 1.56 amateur service: A radiocommunication service for the purpose of self training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest.

RR 1.57 amateur-satellite service: A radiocommunication service using space stations on earth satellites for the same purposes as those of the amateur service.

Some administrations, most notably the USA administration, decided that licensing of many university and commercial research missions in the amateur-satellite service does not comport with the definitions of the amateur services. Instead, licensing is provided as experimental stations in accordance with ART27, despite their having no status with regard to causing or receiving harmful interference.

When the USA administration changed licensing policy in November 2012, many CubeSats, originally coordinated as amateur-satellite stations, were already built, manifested for launch, and already mounted on a launch vehicle. They would have been denied their launch opportunity without cooperation from IARU. After consulting widely a set of terms and conditions to accommodate experimental stations on a *temporary* basis was devised.

The International Amateur Radio Union, through its Satellite Advisor and his advisory panel, continue to provide CubeSat builders with a frequency coordination service to, as far as possible, coordinate frequencies with the lowest possible interference potential to amateurs and to each other. As before, discouraging use of the two-metre band for uplinks has met with limited success. With the rapid growth of CubeSats and launches with large numbers of CubeSats on one launch, it has become very difficult to coordinate frequencies in the two-metre satellite band with a reasonable chance of successful operation.

IARU continues to hold the view that non-amateur satellites, that are satellites with missions inconsistent with RR1.56 and RR1.57, should not be coordinated in amateur service and amateur-satellite service frequency bands. Therefore, IARU recommends that these CubeSat builders look to bands allocated to existing services appropriate for their missions, rather than the two-metre band.

Beginning 1 July 2014, IARU will no longer be able accept frequency coordination requests for experimental stations in the two-metre band. However the IARU will continue to coordinate frequencies in the two metre band for satellites that carry true amateur radio payloads

As an interim solution, non-amateur CubeSat uplinks could be coordinated in the 1260-1270 MHz band.

It is not envisioned that limited frequency coordination will set any precedent for future use of the amateur and amateur satellite bands by non-amateur licensed satellites. IARU is actively participating in discussion to find a solution to this problem.

IARU intends to provide coordination in the two-metre band to the best of its ability for experimental CubeSats that are already designed and being built.

Terms and conditions

The International Amateur Radio Union (IARU) will make best efforts to coordinate frequencies for use by experimental stations and issue a coordination letter provided (1) that the frequency coordination application form is fully completed and signed by the licensee or authorized representative for the experimental license and provided

(2) that the licensee agrees to the following terms and conditions.

1. Experimental stations must accept harmful interference from all stations operating in accordance with the Table of Frequency Allocations and, in the event that the experimental station causes harmful interference, must cease operation immediately upon request from the IARU Satellite Advisor or order by their licensing administration.
2. All space stations must be capable of being turned off immediately by telecommand from associated Earth stations. See: RR 22.1.

22.1 §1 Space stations shall be fitted with devices to ensure immediate cessation of their radio emissions by telecommand, whenever such cessation is required under the provisions of these Regulations.

NOTE: For more information, see [Controlling Space Station Transmitters](http://www.iaru.org/satellite) on www.iaru.org/satellite

3. Sufficient Earth stations must be established and identified to the IARU Satellite Advisor at least 30 days before launch to assure the ability to turn off all space stations immediately upon request, otherwise coordination may be withdrawn.

NOTE: If communicating with stations licensed by another administration, project teams shall make certain BEFORE LAUNCH that the licensing administration has communicated with them appropriately. See: RR 27.1 and 27.2.

27.1 §1 1) An experimental station may enter into communication with an experimental station of another country only after it has been authorized to do so by its administration. Each administration shall notify other administrations concerned when such authorizations are issued.

27.2 2) The administrations concerned determine by special arrangement the conditions under which communications may be established.

4. IARU will make best efforts to coordinate frequencies to help the licensee's project succeed. However, the Satellite Advisor may decline coordination if a frequency in a requested band is likely to cause harmful interference either to amateur or amateur-satellite stations or to an experimental station already coordinated.
5. Frequencies in the amateur and amateur-satellite services are shared and, therefore, cannot be coordinated on an exclusive basis.
6. Coordination of a frequency for a mission does not guarantee that the same frequency will be available for follow-on missions.

7. Licensee agrees to notify the IARU Satellite Advisor of the following events, whenever they occur.
 - a. Experimental station license expiration.
 - b. Launch failure.
 - c. Mission termination.
 - d. Launch date in the coordination request passes without the launch occurring.
8. **COORDINATION EXPIRES** whenever the licensee does not meet a term or condition described here. Whenever any event in Number 7 occurs, *the expiration date may be extended upon request of the licensee.*
9. Command links are as a general rule not coordinated as they are usually limited to one location using highly directive antennas and thus are less likely to cause interference. For reliability reasons the two metre band is not recommended as a preferred band for command links.

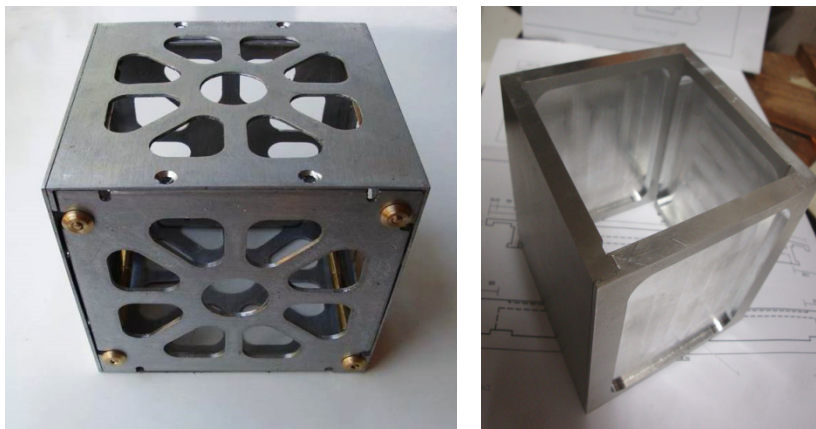
SA AMSAT TURNS TO INNOVATION FOR ITS CUBESAT

Hans van de Groenendaal ZS6AKV

Building a CubeSat can be an easy task if one has the budget to buy a kit of parts and simply assemble it. SA AMSAT does not have the few million required so the team had to go to the drawing board and design as many of their own components as possible.

The project has been name KLETSkous (Afrikaans for Chatterbox). The final name once completed and ready for launch will be decided through a naming competition.

It is challenging task but out of the challenge has come some very innovate solutions. The first proto-type of the space frame showed what can be done in a



First space frame prototype

Garage workshop if one uses ingenuity and work around complicated processes and finds practical ways of achieving the same end-result as a space frame machined in sophisticated workshops overseas. Deon Coetzee, is now building the second prototype using special space qualified aluminium. This frame will be used for the engineering model of the satellite after which he will build the one that goes into space. Doing it yourself can present problems like the first one built form standard aluminium the corners were easy to bend, but the space qualify aluminium does not so. Deon Coetzee has to go back to the drawing board and devise another method using slide in corners. A further prototype is current being machined.

Deon Coetzee has also started work on a deployment system for the antennas and is currently experimenting with a solar panel fold-out mechanism.

The transponder included in the payload is also of unique design and will be the first of its kind to fly on a cubesat. A cubesat is typically 10x10cx10 cm and may not have a mass of more than 1.3 kg. The transponder design is linear which means that it can handle FM and Single Side Band (SSB) signals. The uplink will be in the 70cm band with the downlink in the 2 metre band. With a bandwidth of 20 kHz, the

transponder will be able to handle 2 FM channels or several SSB channels simultaneously.

The design for the transponder was done by Jacques Roux. The design requires minimum tuning using off-the-shelf saw filters, mimic blocks and oscillator Integrated circuits, mixers and automatic gain amplifiers. It was the objective to keep the design as simple as possible without compromising functionality.”

Why A South African Cubesat?

One of the major problems radio amateurs in South Africa experienced with SumbandilaSat’s amateur payload was that the rest of the world were able to enjoy the transponder facilities on almost every pass while when over South Africa much of the resources of the satellite were dedicated to telemetry, commanding operations and the primary payload, the camera. Beside the challenge of building a cubesat, SA AMSAT wanted to have a satellite that could primarily serve the African continent.

Another interesting feature designed in the transceiver is that should the batteries fail, the unit can reboot itself and operate directly from the output of the solar panels. Battery failure in space is a common problem. The command and control system is also at first prototype stage and is the brainchild of Brian Mackenzie. A proto-type will be tested on a high altitude balloon launch to be launched on 30 November 2014.

African Resources Management Constellation of satellites

South Africa, Nigeria, Algeria and Kenya have signed an agreement to develop a constellation of imaging satellites in which each country will contribute one satellite. In South Africa the project kicked-off earlier this year when the Government made funding available to start work on the South African part of the constellation.

SA AMSAT has been in discussions with the South African National Space Agency (SANSA) to have an amateur radio transponder included in the satellite. Negotiations are proceeding well and some basic agreement has been reached on this. The plans are to have the same transponder as the one for KLETSkous included in the payload. At this stage the time frame is to have it launched by 2016.

To follow progress on the KLETSkous and other SA AMSAT projects visit www.amsatsa.org.za

Upcoming Amateur Radio CubeSats: The Flood Has Arrived

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1 Introduction

In the next several months, approximately 58 CubeSats will be launched into space on four upcoming launches. This represents an approximately 50% increase in the number of CubeSats currently orbiting the earth. This expected increase has created strain for licensing and coordinating organizations, such as the Federal Communications Commission (FCC) and the International Amateur Radio Union (IARU).

In this paper, we will review the manifests of these four upcoming launches, explain recent clarifications to the licensing rules, and discuss the downlink frequencies and licensing service for each of the CubeSats.

2 Changes to CubeSat Licensing

As mentioned at several recent workshops [1, 2, 3], the FCC and International Telecommunications Union (ITU) are in the process of clamping down on licensing for small satellites. Only satellites that provide benefit to the amateur radio community, such as a transponder that the average ham operator can use, are allowed to follow the amateur satellite service rules.

The FCC and National Telecommunications and Information Administration (NTIA) are also clamping down on the difference between private or commercial satellites, which obtain a license through the FCC, and government satellites, which acquire a license through the NTIA. Only government-funded and government-operated satellites may apply for a government license through the NTIA; all others must apply through the FCC.

In March 2013, the FCC released a public notice titled “Guidance on Obtaining Licenses for Small Satellites” (DA-13-445). While this document helps clarify the licensing process and rules related to small satellite communications, it does not provide any guidance on which service the satellite operator should select. Many CubeSats still use amateur radio frequencies due to the hardware readily available for those frequencies. Only when satellite and ground station radio hardware on other frequencies is easily available and flight-proven will CubeSats migrate away from amateur satellite frequencies.

3 ORS-3/ELaNa-4

Scheduled for launch in early November 2013, the ORS-3/ELaNa-4 launch is a collaboration between the Operationally Responsive Space (ORS) office and the Educational Launch of Nanosatellite (ELaNa) Program. It is the first launch of the CubeStack Adapter, commonly called the “wafer.” The CubeStack Adapter is built by Moog CSA Engineering, mounts between the upper stage of the rocket and the primary payload, and holds up to eight 3U CubeSat dispensers [4, 5]. This launch in November will include two CubeStack Adapters, with STPSat-3 as the primary spacecraft.

This is the first CubeSat launch for which the FCC encouraged all non-government CubeSats to obtain experimental licenses. The CubeSat integration team, in this case Cal Poly State University, filled out all the appropriate paperwork related to the experimental license, and forwarded the orbital debris and lifetime analysis reports to the FCC. If the radio frequency allocation the team was attempting to obtain fell within the amateur satellite service, the FCC also required a coordination letter from the IARU.

Table 1: ELaNa-4 and ORS CubeSats on the ORS-3 Launch [6, 7, 8].

Satellite	Size	Downlink	License
COPPER	1U	437.290 MHz	Experimental
TJ3Sat	1U	437.320 MHz	Experimental
Vermont Lunar Cube	1U	437.305 MHz	Experimental
SwampSat	1U	437.385 MHz	Experimental
Cape-2	1U	437.325 MHz	Experimental
Ho’oponopono	3U	437.220 MHz	Experimental
PhoneSat 2.0	1U	437.425 MHz	Experimental
Trailblazer	1U	437.425 MHz	Experimental
DragonSat-1	1U	145.870 MHz	Experimental
KySat-2	1U	437.405 MHz	Experimental
Charger	1U	437.405 MHz	Experimental
NPS-SCAT	1U	437.525 MHz	Government
Black Knight 1	1U	437.345 MHz	Government
ORS 1	3U		Government
ORS 2	3U		Government
ORS 3	3U		Government
Prometheus 1	3U		Government
Prometheus 2	3U		Government
Prometheus 3	3U		Government
Prometheus 4	3U		Government
SENSE 1	3U	2.2 GHz	Government
SENSE 2	3U	2.2 GHz	Government
FireFly	3U	425 MHz	Government
Horus	3U	915 MHz	Government

4 ISS Launch

Organized by NanoRacks, the four CubeSats described below were brought up to the International Space Station (ISS) on the Japanese HTV-4 vehicle in March 2013. They are expected to be deployed from the two Japanese J-SSOD deployers in early November 2013.

The ISS launch contains two identical ArduSat 1U CubeSats, financed through crowd funding and built by NanoSatisfi. Each satellite contains 17 ATmega328P Arduino processors, and a suite of sensors. The general public can rent time on the spacecraft to perform basic experiments for a nominal fee [9]. The third CubeSat, Pico Dragon, is a 1U CubeSat developed by the Vietnam Academy of Science and Technology, and will take pictures of the earth. The fourth CubeSat, TechEdSat-3, contains an advanced avionics system, and the main payload is an exo-brake passive de-orbit system [10].

All the CubeSats on this launch are in the UHF amateur satellite band, but only Pico Dragon is licensed under the amateur satellite service, as shown in Table 2.

Table 2: CubeSats deployed from the ISS [9].

Satellite	Size	Downlink	License
ArduSat-1	1U	437.325 MHz	Experimental
ArduSat-X	1U	437.345 MHz	Experimental
Pico Dragon	1U	437.250 MHz	Amateur Satellite
TechEdSat-3P	3U	437.465 MHz	Experimental

5 Dnepr

The Dnepr rocket is scheduled to be launched in late November 2013 from the Dombarovsky launch site in Yasny, Russia. The rocket will transport 18 CubeSats and 5 PocketQubs into a 720 km orbit at 98 degrees. This is the biggest launch of secondary satellites since the Dnepr-1 launch crashed in July 2006. Some of the satellites of interest to the amateur radio community on this launch include:

FUNcube-1 is built for AMSAT-UK by Innovative Solutions in Space (ISIS), and contains a 20 kHz inverting linear transponder, with the uplink at 435.140 MHz and the downlink at 145.960 MHz. It also contains a BPSK telemetry channel at 145.935 MHz [11].

ZACube-1 is the first CubeSat from South Africa, and contains a 14.099 MHz HF beacon. This will be used as an on-orbit source for ionospheric measurements for the DARN network over Antarctica.

Delfi-n3xt also contains a linear transponder, an earlier version of the one inside FUNcube-1. It will be activated some of the time [12].

TRITON-1 contains an amateur radio transponder that will activate when the primary mission of AIS ship tracking ends.

ISIS provides launch integration and launch support services for the first 9 ISIPODs listed below in Table 3, and the rest of the CubeSats and PocketQubs will be deployed from UniSat-5.

UniSat-5 is a microsatellite, approximately 45 cm on each side, built by the GAUSS team at the University of Roma La Sapienza in Italy. It contains custom-built deployers for four CubeSats and four PocketQubs. The four CubeSats inside UniSat-5 will be deployed from two Planted Elementary Platforms for Picosatellite Orbital Deployment (PEPPOD). The PUCP-SAT-1 1U CubeSat will deploy the Pocket-PUCP PocketQub.

UniSat-5 will also launch the first PocketQubs, a femtosatellite standard conceived by Professor Bob Twiggs at Stanford University in 2009 [13]. At approximately 50 mm per side and less than 125 grams (roughly one-eighth the size of a 1U CubeSat), these PocketQubs are deployed from a Morehead Roma Femtosat Orbital Deployer (MR-FOD). Each MR-FOD can hold two 1Q-sized PocketQubs. UniSat-5 contains three MR-FOD deployers.

Table 3: CubeSats and PocketQubs on the Dnepr Launch [12, 14, 15].

Satellite	Size	Downlink	License
FUNcube-1	1U	145.960 MHz	Amateur Satellite
ZACube-1	1U	437.345 MHz	Amateur Satellite
HiNcube	1U	437.305 MHz	Amateur Satellite
First-MOVE	1U	145.970 MHz	Amateur Satellite
UWE-3	1U	437.385 MHz	Amateur Satellite
Velox-PII	1U	145.980 MHz	Amateur Satellite
NEE-02 KRYSAOR	1U	980 MHz	Experimental?
CubeBug-2	2U	437.445 MHz	Amateur Satellite
KHUSAT-1	3U	2.2 GHz	Space Research
KHUSAT-2	3U	2.2 GHz	Space Research
TRITON-1	3U	145.815 MHz	Amateur Satellite
Delfi-n3xt	3U	145.900 MHz	Amateur Satellite
OPTOS	3U	402 MHz	Earth-exploration Satellite
Dove-3	3U	8.2 GHz	Experimental
PUCP-SAT-1	1U	145.840 MHz	Amateur Satellite
Pocket-PUCP	1Q	437.200 MHz	Amateur Satellite
ICUBE-1	1U	145.947 MHz	Amateur Satellite
HUMSAT-D	1U	437.325 MHz	Amateur Satellite
Dove-4	3U	8.2 GHz	Experimental
SWESat (Eagle-1)	1Q	437.465 MHz	Experimental
\$50sat (Eagle-2)	1Q	437.505 MHz	Experimental
QBScout-S1	2Q	437.525 MHz	Experimental
WREN	1Q	437.405 MHz	Amateur Satellite

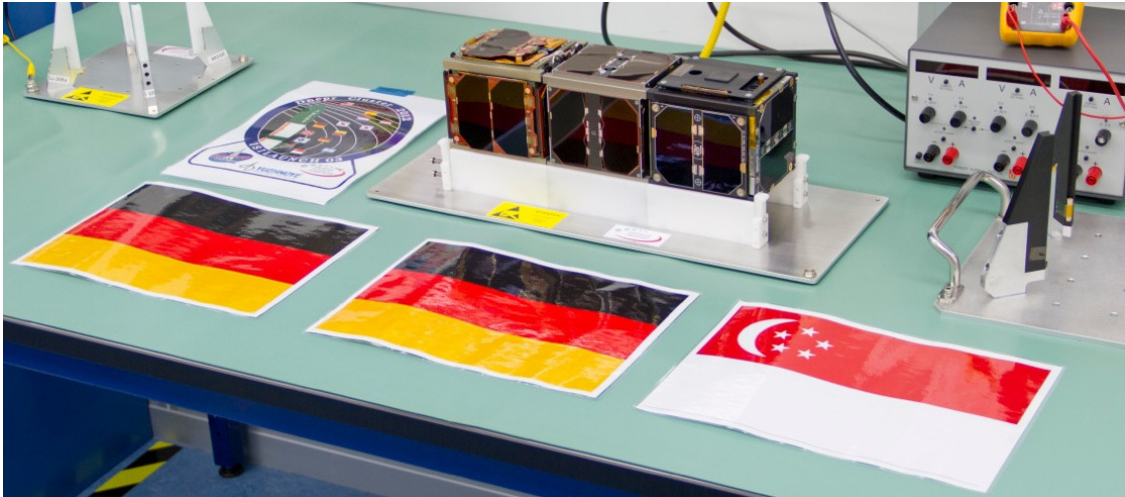


Figure 1: First-MOVE, UWE-3, and Velox-PII CubeSats before integration into the ISIPOD [16].

6 NROL-39/ELaNa-2

This joint NRO and NASA launch is scheduled for early December 2013 from Vandenberg, California. Also called GEMSat, the deployer is a Naval Postgraduate School CubeSat Launcher (NPSCul) mounted to the aft bulkhead carrier of an Atlas V rocket. The NPSCul was built by students at the Naval Postgraduate School. The CubeSats on this launch include:

IBEX, which contains an FPGA payload for the Jet Propulsion Laboratory, and was built by Cal Poly State University [17].

CUNYSat-1, which contains a GPS radio occultation receiver, and was built by students at Medgar Evers College in the City University of New York.

FIREBIRD, which is a two 1.5U mission built by Montana State University for the National Science Foundation. It will look at relativistic electron bursts in the magnetosphere [18].

The GEMSat integration team, consisting of Cal Poly State University, SRI International, and NPS, managed the CubeSat integration and coordinated the frequency license applications.

Table 4: CubeSats on the ELaNa-2 launch [19, 20].

Satellite	Size	Downlink	License
IBEX	1U	437.270 MHz	Experimental
MCubed-2	1U	437.485 MHz	Experimental
CUNYSat-1	1U	437.505 MHz	Experimental
FIREBIRD A	1.5U	437.405 MHz	Experimental
FIREBIRD B	1.5U	437.230 MHz	Experimental
Alice	3U	915 MHz	Government
Aerocube-5a	1.5U		Experimental
Aerocube-5b	1.5U		Experimental
SMDC-ONE 2.2	3U		Government
SMDC-ONE 2.3	3U		Government
TacSat-6	3U		Government
SNAP	3U		Government

7 Conclusion

If the four launches happen with minimal delays, the upcoming months promise to be very exciting for the UHF amateur radio spectrum. Many new CubeSats and PocketQubs will be on orbit, and every launch will create a scramble to match satellites with object numbers.

Progress is also being made on licensing support for CubeSat developers. Launch integrators are now required by their funding agencies and mission managers to provide technical and logistical support for frequency selection and license acquisition, including the actual filing of the experimental licenses. This process ensures uniformity, completeness, and coordination of applications, thereby reducing some of the strain on the FCC and IARU. While this frequency licensing support is currently provided for US ELaNa launches only, it is recommended that international launch integrators provide these services.

To encourage CubeSats to move away from amateur radio frequencies, a recent meeting at the SmallSat Conference in Logan, Utah, was convened by the author to discuss emerging hardware radio solutions. Meeting participants discussed many high-speed data radio projects that use non-amateur frequencies in S-band, C-band, X-band, and Ka-band [21, 22, 23, 24].

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Cubesats in HEO - A Challenging Mission for AMSAT

Daniel Schultz, N8FGV

The inexpensive launches to High Earth Orbit (HEO) that AMSAT enjoyed in previous decades are gone, probably forever. The hosted payloads on geosynchronous satellites have not yet materialized either. There was a time when AMSAT was the only small satellite organization in existence, but our success in building and launching small satellites over the last five decades has resulted in a vigorous industry for secondary payloads, and today we have to compete with, or work with, many other entities if we are to return amateur radio to HEO.

The launch agencies that might provide a low cost launch for an AMSAT Cubesat are not interested in our need to communicate with rare grid squares or distant DX countries. The only way to obtain a free launch from the NASA ELaNa program or other agencies will be to address:

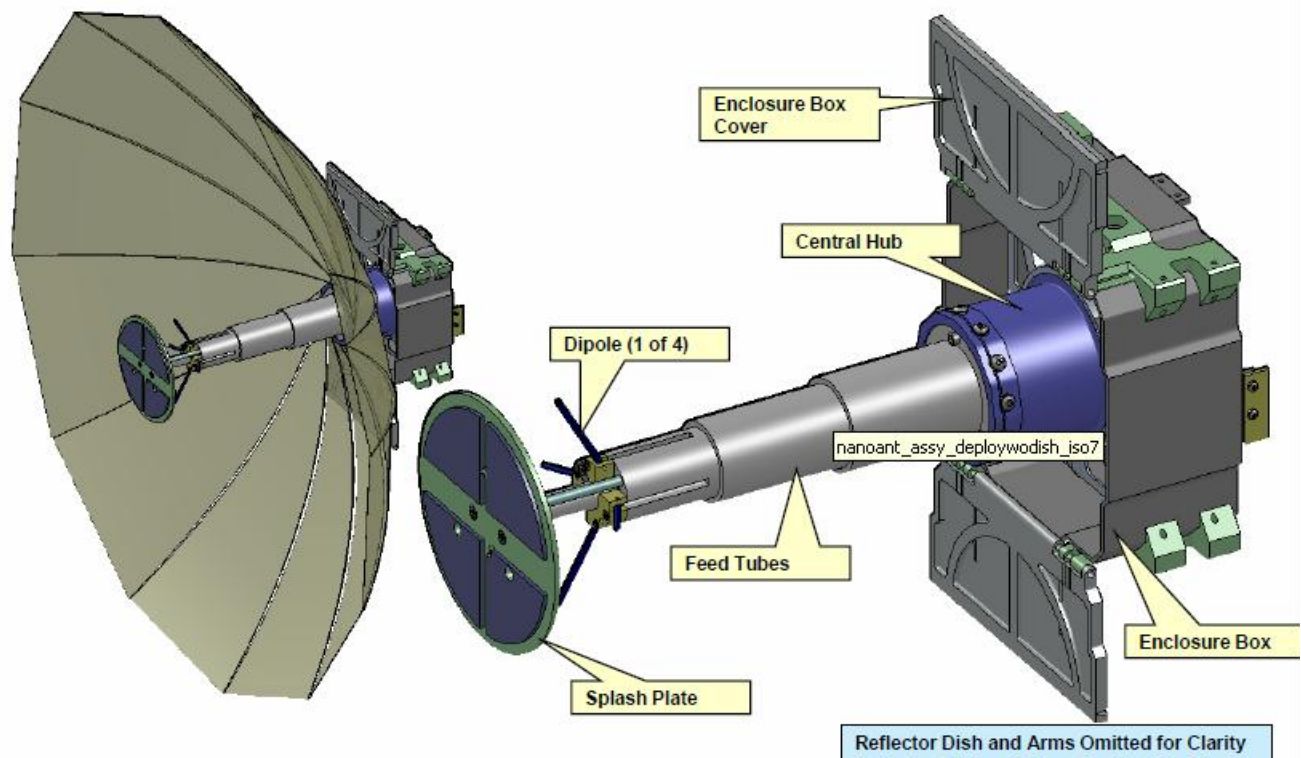
1. Educational outreach and training of new spacecraft engineers. (ARRISat)
2. Technology demonstration and flight qualification. (RadFX satellite)
3. Low cost science missions. (TBD)

The Cubesat standard has taken over all secondary satellite launches, largely because the standardized launch vehicle interface is highly attractive to launch authorities. As a result of this "Attack of the Cubesats" (1), it seems likely that all future AMSAT missions will need to fit the Cubesat standard, which presents the great challenge of how to pack a fully capable communications mission into a tiny little Cubesat package. However the commercial and government world has been inventing very clever solutions to extract high performance from tiny Cubesats to implement serious missions, and AMSAT had best keep abreast of these developments or ignore them at our peril. The Proceedings of the annual AIAA/USU Conference on Small Satellites (2) are an excellent resource to see the amazing things that other groups are doing with Cubesats.

Getting our satellite to a HEO orbit is the primary challenge, with most launches delivering Cubesats to LEO, some sort of propulsion system will be needed to raise the orbit. However there also a possibility of deploying from a Geosynchronous Transfer Orbit (GTO) launch that would greatly decrease the energy needed to reach HEO (3). At least one recent classified mission may have been injected directly into a Molniya orbit (4), a secondary payload carried on that flight could have reached the same orbit with little or no additional propulsion. As we learned with AO-13, a small thruster on a Molniya satellite could still help a lot in avoiding the orbital resonance that eventually ended the AO-13 mission.

Electric propulsion is a mature technology that can propel our satellites to the desired orbits (5), but the price of ready to fly commercial COTS thrusters and systems is more than AMSAT can afford to pay. However there is a possibility that some of the electric thruster companies or universities might work with AMSAT in flying developmental thrusters on AMSAT missions to prove their performance to potential commercial customers (6).

There are a great many Cubesats being launched to Low Earth Orbit (LEO), where the communications link budget is fairly easy with low gain whip antennas. Fewer Cubesats are being designed for HEO because of the much greater challenge of communicating with a tiny little satellite so far from Earth. To provide a useful amateur radio mission in HEO we must provide sufficient transmitter power and antenna gain to allow reception by modest antennas at the ground stations. There is little point in launching a satellite that would require an EME class ground station to hear its downlink.



Deployable S-band dish antenna for Cubesats – Taken from Ref #7

A very interesting development from the commercial Cubesat world is a deployable half-meter wire mesh dish that has been designed for the University of Southern California's Aeneas mission (7)(8). This program proposes to track shipping containers across the ocean using 1 watt WiFi hardware at 2.4 GHz. The same antenna would provide 18 dB of gain in the 13 centimeter amateur satellite band, if we can obtain this technology at a reasonable cost. A group at MIT is also developing an inflatable S-band antenna for Cubesats, but this may not be able to support the ten-year mission that we desire. The use of an array of patch antennas in a phased array might also work without the risk of using another deployable mechanism. All of these antennas will require three axis attitude determination and control, which AMSAT has yet to successfully demonstrate in space.

A 50 watt S-band transmitter feeding a half meter dish antenna could come close to the performance of the highly successful AO-40 S-band downlink, which was received by many amateurs using small dishes and inexpensive S-band down converters. A single 20 x 30 cm 18 cell solar panel deployed from a 6U Cubesat would generate about 18 watts at beginning of life (9). A pair of such panels would provide 36 watts; deploying four such panels would generate 72 watts. I have heard of estimates by other Cubesat builders that a 6U Cubesat should be able to generate 100 watts. A satellite with smaller solar arrays will be proportionally limited in its power output, leading to the need for AMSAT to discuss with its members and users just how much of a satellite they are willing to pay for, verses how much they want to spend on their ground station antennas. A low power satellite in HEO will not be an "EZ sat", and will lead to much complaining on amsat-bb that we are only interested in serving the elite hams.

The next round of NASA ELaNa launch proposals is due November 22. They are accepting proposals for up to 6U Cubesat missions (10). AMSAT should prepare a proposal for this cycle in order to register our interest in obtaining a launch on a GTO mission if possible, otherwise NASA and other launch agencies may decide that there is no interest in GTO launch opportunities from the Cubesat

community and may not include Cubesat deployers on these launches.

REFERENCES:

1. **"Attack of the CubeSats: A Statistical Look"**

Michael Swartwout, Saint Louis University

<http://digitalcommons.usu.edu/smallsat/2011/all2011/39/>

2. **Proceedings of the AIAA/USU Conference on Small Satellites: 1987 to 2013**

<http://digitalcommons.usu.edu/smallsat/>

3. **"ELaNa - Educational Launch of Nanosatellites - Still Moving Forward!"**

Garrett Skrobot, CalPoly Spring Workshop 2013

http://www.cubesat.org/images/cubesat/presentations/DevelopersWorkshop2013/Skrobot_ELaNa.pdf

4. **Gunter's Space Page: "'Trumpet F/O' 1, 2, 3"**

http://space.skyrocket.de/doc_sdat/trumpet-fo.htm

5. All of the papers from the **2013 International Electric Propulsion Conference** are available at:

<http://www.iepc2013.org/agenda>

6. **"Iodine Propellant Space Propulsion"**, IEPC-2013-311

James Szabo, Mike Robin, Surjeet Paintal, Bruce Pote, Vlad Hruby, Chas Freeman
Busek Co. Inc, Natick, MA, 01760, USA

<http://www.iepc2013.org/get?id=311>

7. **"Aeneas -- Colony I Meets Three-Axis Pointing"**

Michael Aherne, Tim Barrett, Lucy Hoag, Eric Teegarden, Rohan Ramadas

Proceedings of the 2011 AIAA/USU Conference on Small Satellites,

<http://digitalcommons.usu.edu/smallsat/2011/all2011/85/>

8. **"Miniature Deployable High Gain Antenna for CubeSats"**

Charles S. "Scott" MacGillivray, Boeing Defense, Space & Security (BDS) / Phantom Works

Advanced Network & Space Systems Group, Huntington Beach, CA

http://mstl.atl.calpoly.edu/~bklofas/Presentations/DevelopersWorkshop2011/47_MacGillivray_Miniature_Antennas.pdf

9. **Clyde Space 6U Solar panel**, 18 cells, 18 watts BOL at 28 degC, price \$14,650

<http://www.clyde-space.com>

10. **NASA CubeSat Launch Initiative** (not working as of press time due to government shutdown)

http://www.nasa.gov/directorates/heo/home/CubeSats_initiative.html

Additional Resources:

Annual International CubeSat Workshop

<http://www.cubesat.org>

Interplanetary Cubesat Workshop

<http://icubesat.org>

Pumpkin Cubesat Kit

<http://www.cubesatkit.com>

Cubesat Shop

[CubeSatShop](#)

AMSAT Fox-1 Systems Engineering Documentation

**By Jerry Buxton, N0JY
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The AMSAT Fox program introduced a new engineering process for AMSAT in which engineering documentation is provided at each stage of development. We are archiving all of this documentation on an on-line, backed-up, version control server. When the satellite has been completed, we will have an archive of traceable documentation. This can serve as the basis for planning and executing future satellite programs and can be updated to apply the lessons learned of what went well and what did not.

AMSAT is a truly unique organization in that we are a non-profit corporation that manufactures satellites using a geographically distributed, all-volunteer engineering staff. There are no common or established guidelines to cover our situation. As such, the Fox program engineering practices are themselves an evolving process. The practices used are drawn from industry sources, especially NASA¹ and IEEE.

AMSAT has adopted a common industry scheme known as numbered requirements. Each individual requirement has a unique number assigned to it. The number allows a very precise reference to a specific requirement and this enhances the overall traceability of the specifications. The requirements are tracked throughout the documents using requirements tracking software, from the ConOps down to the test results, in order to verify that all requirements are properly implemented by the various systems that make up the satellite.

Due to US State Department ITAR² restrictions, our document server is only available to project members who have been vetted to meet the requirements for a "US-person." AMSAT, as an educational organization, would like to publicly release the majority of our design documentation to serve as a learning tool to anyone interested in satellite development. However, this must be done in a specific way to meet the ITAR requirements. The information must first be released via an openly available publication. We would also like to be able to discuss our satellite projects with our own members, some of whom are not "US-persons" per ITAR. These AMSAT Space Symposium proceedings provide a convenient mechanism for the needed publication in order to make this information public domain and allow us to communicate with our members.

While many of these documents were published in the *Proceedings of the AMSAT-NA 30th Space Symposium and AMSAT-NA Annual Meeting*, most of these documents have undergone changes as the satellite design has progressed and evolved and so they will be reproduced in these 2013 Space Symposium proceedings. In addition, these proceedings also present new engineering documents that have been produced since the last publication.

An introduction to these documents follows.

The ConOps document is the original form describing the expectations of the satellite. It is the governing document from which all development is derived.

The System Requirements Specification is a document that provides the top level technical specifications derived from the ConOps. This document describes what the system should do. The inputs, outputs, functions, mass, volume, environment and other external characteristics are included and specified in the system requirements. The level of detail for each requirement is specifically chosen to provide a clear definition of what the systems will do without too much specific detail or declaring how it will be done. This allows the engineers latitude in designing the best approach to satisfying the requirement.

The Avionics System Design Specification is a document that provides specific details of how the avionics system will be designed. The specifications are based on best design choices determined by the teams. The signals, connections, connectors, volume, and requirements specific to each system are stated in this document so that each system will fit together and function with the other systems.

The Experiment Payload Requirements are requirements written for the Penn State student designed attitude determination system. The actual system designed by the students was not constructed before their graduation. The experiment payload system design is incorporated onto the IHU board.

The Interface Control Documents (ICD) for the IHU to Attitude Determination Experiment, IHU to RF System, IHU to PSU, IHU to Battery, IHU to Experiment 1, and IHU to Experiment 4 set the requirements for connections and communication between the IHU and the various systems. Each of the systems sends telemetry measurements and other signals to the IHU. The IHU sends telemetry audio and control signals to the RF System and controls the experiments. The ICD allows the systems teams to work on their systems knowing that their systems will interface successfully.

The Downlink Specification Document sets the requirements for the downlink protocol and the data to be sent in the slow and high speed downlinks. This allows the satellite and ground station software teams to send the information to the ground and recover the data successfully.

The IHU Software Architecture Specification provides the design specifications needed for the software design and operation of the Internal Housekeeping Unit.

The engineering documents published in these proceedings are what was available at time needed for inclusion and we hope you find them interesting and informative. AMSAT intends to continue to make the majority of the final technical documents, exclusive of satellite control information, available in future publications.

¹ NASA Systems Engineering Handbook, NASA/SP-2007-6105 Rev1

² International Traffic in Arms Regulations, see:

http://www.pmdtc.state.gov/regulations_laws/itar_official.html

Date: October 19, 2011
Version: 1.03

AMSAT *Fox-1* Satellite Concept of Operations

1 Introduction

The AMSAT *Echo* satellite, also known as AO-51, has been the most widely used amateur satellite due to its ability to provide basic radio communications with very simple ground station equipment. It provides an FM repeater function that has very wide geographical coverage allowing amateur radio operators to communicate over substantial distances using just a handheld transceiver (i.e. a *walkie-talkie*) and a small handheld antenna. This type of satellite operation is often referred to as the *EasySat* mode due to its simplicity. It is extremely valuable in providing an introduction to satellite communications and is often used for demonstrations given at schools, to scouting organizations and at amateur radio publicity events.

After 6 years of service, *Echo* is nearing the end of its life due to battery failure. For the sake of our space education and outreach activities, it is essential that AMSAT quickly provide a replacement for *Echo* that can continue to provide access to the *EasySat* mode. The *Fox-1* satellite is intended as this replacement.

Building on a harsh lesson learned from *Echo* and inspired by the longevity of AO-7¹, the *Fox-1* satellite project will introduce the concept of *designed-in*, partial-failure operation. The satellite will be specifically designed so that when the battery fails, the transponder can continue to operate when the satellite is in sunlight. Similarly, the satellite will be designed so that the FM transponder can operate without relying on ground control or a functioning processor in the IHU. These modes are intended to extend the usable life of the satellite.

In addition to its primary mission as a communications satellite, the *Fox-1* satellite will host an experiment payload. Over the past two academic years, AMSAT has sponsored senior design *capstone* projects to engage university students in a real-world engineering experience. The AMSAT projects have focused on aspects of CubeSat design and construction. Building on this success, one of the AMSAT sponsored student projects for the 2011-2012 academic year at Penn State University will be to provide the experiment payload that will be flown on the *Fox-1* satellite. This experiment is a technology investigation that is of interest to AMSAT.

Our previous spacecraft have often used passive magnetic attitude stabilization. While the results have been satisfactory, we have no actual data on how well this mechanism works. Large spacecraft with much higher power budgets have a substantially larger margin of error with little ill effect. But the error in the stabilization of the antenna system on a CubeSat is far more of a concern since the transmitter power is very limited. Additionally, we have typically had to analyze the telemetry data on the ground to try to ascertain the satellite spin rate about its magnetic axis. The objective of the student

experiment is to directly measure the satellite spin rate and direction as well as the "wobble" about the magnetic axis using a 3-axis micro electro-magnetic gyroscope and to provide this information in telemetry to the ground.

AMSAT expects to submit a proposal to the NASA ELaNa² program for a low-cost launch of this satellite. Proposals will be due in November of this year. If accepted, the launch would be in the 2013 time frame. While AMSAT believes that this project would nicely address the goals and objectives of the NASA program, there can be no guarantee that the proposal will be accepted. However, AMSAT would still be free to purchase a market-rate launch of this satellite through any of the CubeSat launch integrators such as Cal-Poly.

1.1 Document History

DATE	VERSION	SUMMARY
Sept 20, 2011	1.00	Base Version
October 8, 2011	1.01	Req. 3.3 updated to 45 min. for NASA LSP-REQ-317.01, added ref. to NASA LSP-REQ-317.01 in sec. 5, added document history in 1.1
October 9, 2011	1.02	Added Requirements Tracking
October 19, 2011	1.03	Update information on student experiment

1.2 Program Goals and Objectives

The AMSAT Fox-1 satellite program is intended to:

1. Provide an on-orbit FM transponder to allow wide-area communications between amateur radio operators using simple ground-station equipment.
2. Develop a 1U CubeSat design that can host an experiment payload.
3. Promote closer relationships with universities including student development of satellite components and subsystems.
4. Implement a new engineering process that will improve AMSAT's ability to plan, manage and finance satellite projects.
5. Implement an engineering process that will meet the requirements for submission of proposals to the NASA ELaNa program.
6. Provide required software needed by the AMSAT Operations team to operate the satellite in orbit and to collect and archive telemetry and experiment data.
7. Complete the satellite development in time for a 2H 2013 launch.

1.3 Mission Overview

The primary mission of the satellite is to provide a wide-area, amateur radio communications capability that can be accessed using very simple ground station equipment such as a handheld FM transceiver paired with a small, handheld beam antenna. The satellite communications transponder will employ analog, narrow-band FM

like that typically used on the amateur radio VHF and UHF bands. The satellite is expected to support the primary mission for at least 5 years in orbit.

The secondary mission of the satellite is to host an experiment payload. The radio communications capabilities of the satellite will be used to uplink control commands for the experiment as needed and to downlink data collected from the experiment to ground stations.

1.4 Document Scope

The purpose of this Concept of Operations (CONOPS) document is to describe the satellite system and how it will be used. This is not a requirements document but provides operational context that should be helpful in developing and understanding system requirements and interface specifications.

2 System Description

2.1 Spacecraft

The *Fox-1* satellite is expected to have the following features and characteristics:

- 1 Unit CubeSat
- 650 km, sun-synchronous, circular orbit
- FM analog transponder
- 400 mW or greater RF power output
- Uplink on 70 cm band
- Downlink on 2 meter band
- Experiment payload
- Permanent magnetic stabilization
- Deployable antennas (no other deployables)
- Fixed solar panels on all 6 sides for power
- Rechargeable battery to support operation during eclipse
- Simple IHU based on a 16-bit microcontroller
- Proprietary scheme for control uplink
- FSK for sending telemetry and experiment data

This list is preliminary and is subject to change. Please note that this CONOPS is not the controlling document for satellite technical specifications.

2.2 Telemetry and Experiment Data

Telemetry data consists of monitored points that provide a measure of the satellite health. The satellite will autonomously measure these points and transmit them on the downlink.

Experiment data will be collected as per the requirements of the experiment and will be stored and/or transmitted as needed.

The telemetry and experiment data, will be transmitted in the clear allowing any ground station to receive it. The information needed to demodulate and decode the downlink signal will be placed in the public domain. An open-source, software package for decoding the telemetry and experiment data will be made available by AMSAT.

2.3 Satellite Commands

The satellite will accept commands from a control station. These are used to control the mode and operation of the satellite. Commands are intended to be limited to use by authorized stations only. Private codes and/or unpublished information will be required to command the satellite.

2.4 Ground Control Stations

It is expected that control stations will not require any specialized radio equipment but may need to be able to generate higher radiated power levels than typical for users in order to gain control of the satellite. This could be accomplished with a high-gain Yagi antenna and/or a high-power amplifier.

In order to command the satellite, specialized software will likely be required. This software will be provided as part of the satellite development effort.

2.5 Amateur Radio User Stations

This satellite will use radio standards commonly used on the amateur radio VHF and UHF bands and will not require any specialized equipment for normal operation. A handheld, dual-band FM transceiver paired with a small hand-held Yagi antenna should be considered a typical user station. Operation with fixed, omni-directional antennas should also be possible with typical amateur radio base and mobile transceivers.

3 Satellite Operational Modes

3.1 Quiescent Mode

This mode will be used when the satellite is flight ready but has not yet been integrated into the deployer (P-POD.) A "*Remove Before Flight*" pin, inserted into its receptacle on the satellite, will disconnect the battery and prevent any operation of the avionics.

3.2 Deployer (P-POD) Mode

After the satellite is integrated with the deployer, the "*Remove Before Flight*" pin will be pulled but deployment switches on the satellite will prevent power-up of the avionics. In this mode, a test umbilical cable can be connected to a port on the satellite which will allow the avionics to be powered, the battery to be charged and diagnostic tests to be run. Once a CubeSat has been integrated with its deployer and the launch acceptance tests have been run, the only way to know if a satellite is still functional is via these diagnostic tests. Therefore, the diagnostics should be as thorough as possible within the limitations of the deployer environment.

3.3 Startup Mode

When the satellite is released in orbit, the deployment switches on the satellite will be activated allowing the satellite to power up. At this point, the satellite will enter Startup Mode. The satellite will time a 45-minute interval and then deploy the antennas. This delay is required by the CubeSat Design Specification. After deploying the antennas, the satellite will enter Transponder Mode.

3.4 Transponder Mode

In Transponder Mode, signals appearing on the uplink will be repeated on the downlink. Amateur radio user stations can use the satellite for general communications with each other. The satellite will simultaneously send telemetry data on the downlink using the frequency spectrum below the audible range so as not to interfere with transponder communications.

The satellite will also monitor the uplink frequency for a command from a control station. A control station can command the satellite to enter Command Mode.

3.5 Command Mode

Command Mode is intended to support experiments that require more satellite resources than can be provided in Transponder Mode. This would include more power and higher downlink data rates.

In Command Mode, signals appearing on the uplink will not be repeated on the downlink. The satellite will use the downlink exclusively to send telemetry and experiment data. It will also monitor the uplink for commands from a control station.

After 24 hours, the satellite will automatically return to Transponder Mode unless another command is received. For multi-day experiments, a control station would need to send a command at least once a day to the satellite to keep it in Command Mode. A control station can also directly command the satellite to enter Transponder Mode.

3.6 Transmitter Inhibit

In order to meet FCC requirements, the satellite will accept a control station command to inhibit the transmitter regardless of the operating mode. Once inhibited, the transmitter will not be activated under any conditions but the satellite will continue to monitor the uplink for commands. A control station can send a command to remove the inhibit and re-enable the transmitter.

3.7 Partial Failure Operation

Partial failure tolerance is intended to extend the usable life of the primary mission of the satellite. An experiment may or may not be operable under a partial failure scenario.

3.7.1 Battery Failure

If the battery deteriorates or fails completely including a short circuit, the satellite will continue to operate on its solar panels while in the sun. In eclipse, the satellite may power down. When back in sunlight, the satellite will automatically enter Transponder Mode.

3.7.2 IHU Processor Failure

The satellite will operate in Transponder Mode by default and will not require intervention from a ground control station. If the processor on the IHU fails, there may be limited control of the satellite and limited or no telemetry data available but the transponder will continue to operate.

4 Mission Operations Overview

The AMSAT operations and engineering teams will work together to commission the satellite after launch. Commissioning is expected to last for only a few days to insure the satellite is operating nominally. After commissioning, the satellite will be turned over to the operations team. It is expected that the operations team would then open the satellite for general communications use by any licensed amateur radio station.

When required for experiment operation, an authorized control station can command the satellite to enter Command Mode. This will turn off the repeater function and enable the transmission of the telemetry and experiment data. When this data transfer has been completed, the authorized control station can command the satellite to return to Transponder Mode.

It is expected that the AMSAT operations team will collect and archive all telemetry and experiment data and make it freely available on the Internet.

5 Reference Documents

1. CubeSat Design Specification Rev. 12. by The CubeSat Program Cal Poly SLO available from: <http://www.cubesat.org/images/developers>
2. ITU Radio Regulations, Edition of 2008. available from <http://www.itu.int/publ/R-REG-RR-2008/en>
3. Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document LSP-REQ-317.01 Revision Basic (from NASA)

¹ AMSAT OSCAR 7 (AO-7) was launched in 1974 and failed in orbit in 1981 when its battery short-circuited. In 2002, at least one of the battery cells opened up allowing the satellite to resume operation when the solar panels are illuminated. As of July 2011, after 37 years in space, AO-7 continues to be operational in sunlight.

² Information on the NASA Educational Launch of NanoSatellites (ELaNa) program can be found on the NASA web site: http://www.nasa.gov/offices/education/centers/kennedy/technology/elana_feature.html

Date: August 20, 2013
Version: Version 1.4

AMSAT *Fox-1*

System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project. This 1 Unit CubeSat is a part of the AMSAT Fox program and includes a subset of the technical capabilities envisioned for the overall program.

Fox-1 is specifically intended as a replacement for the failing AMSAT *Echo* (i.e. AO-51) satellite. *Echo* has been the most widely used amateur satellite due to its ability to provide basic radio communications with very simple ground station equipment. Its FM repeater provides very wide geographical coverage allowing amateur radio operators to communicate over substantial distances using just a handheld transceiver (i.e. a *walkie-talkie*) and a small handheld antenna. This so called "*EasySat*" mode is extremely valuable in providing an introduction to satellite communications and is often used for demonstrations given at schools, to scouting organizations and at amateur radio publicity events. *Fox-1* will not duplicate all of the features and modes of *Echo* but its primary mission is to provide an FM Transponder in order to allow continued access to this *EasySat* mode of communications.

In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

1.1 Document History

DATE	VERSION	SUMMARY
October 5, 2011	1.0	From Draft E
October 8, 2011	1.01	Fix typos in sections 1.2 and 3.5
October 9, 2011	1.02	Add Requirements Tracking
October 23, 2011	1.03	Additional Requirements Tracking
February 21, 2012	1.04	Update Section 3 and Formatting changes
April 18, 2012	1.05	Correction in Section 4
April 22, 2012	1.06	Correct link in Section 1.4 item 2
April 29, 2012	1.1	Revised 3.12.3, 3.12.7, 3.12.8, 3.13.3, 3.13.4, figure 1 to remove RESET and add IHU OFF and IHU ON commands
August 2, 2012	1.11	Added hidden text for requirements tracking to be shown in System Design Specification
September 4, 2012	1.12	Added the previously missing "Table 6" label
October 17, 2012	1.2	Changed mode descriptions in 3.13.1 Table 6; changed 3.9.2, 3.9.3, 3.9.4, 3.9.5, 3.9.6, 3.9.7 to reflect IHU involvement; changed COMMAND MODE to DATA MODE
April 25, 2013	1.3	3.10.2 Remove PA Temperature, add TX T as RF Transmitter Temperature, OSC T as referring to TX oscillator no longer measured changed to read RX oscillator only
August 20, 2013	1.4	Requirements 3.5.5, 3.6.1, 3.9.6, 3.10.2, 3.11.1, 3.12.4, 3.12.6, 3.13.7.1, 3.13.7.2, 3.13.8, 3.13.9 modified, removed or added to reflect the evolving satellite design

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the satellite at the system (i.e. "black box") level. It is intended to be used by the hardware, software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity is *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-1*, Concept of Operations, Version 1.0, September 19, 2011
2. CubeSat Design Specification Rev. 12. by The CubeSat Program Cal Poly SLO available from: http://www.cubesat.org/images/developers/cds_rev12.pdf
3. Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document LSP-REQ-317.01 Revision Basic (from NASA)
4. ITU Radio Regulations, Edition of 2008. available from <http://www.itu.int/publ/R-REG-RR-2008/en>

2 General Requirements

2.1 CubeSat Requirements

- 2.1.1 The satellite shall meet the requirements specified in the CubeSat Design Specification Rev. 12.
- 2.1.2 The satellite shall meet the requirements specified in the NASA LSP-REQ-317.01 Revision Basic.
- 2.1.3 The satellite shall meet the requirements for a 1 unit (single) CubeSat.
- 2.1.4 The satellite shall provide mass for an experiment payload up to 100 g.
- 2.1.5 The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.

2.2 Environmental Requirements

- 2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.
- 2.2.2 The satellite shall be designed to operate in a 650 km, sun-synchronous, circular orbit.
- 2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3 Reliability Requirements

- 2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

2.4 RF Frequency Requirements

- 2.4.1 All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.
- 2.4.2 All satellite uplinks shall be in the 70 cm band of the amateur satellite service.
- 2.4.3 All satellite downlinks shall be in the 2 meter band within the amateur satellite service.
- 2.4.4 All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.
- 2.4.5 All satellite frequencies shall be coordinated with the IARU.

Note that the band plan with the actual coordinated frequencies will be specified in a separate document.

3 Functional Requirements

3.1 Antenna System

3.1.1 The satellite shall include a deployable antenna system.

3.2 Attitude Control

3.2.1 The satellite shall incorporate passive magnetic stabilization to align the deployed antennas with the magnetic field of the earth.

3.3 Access Ports

3.3.1 The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.

3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.

3.4 Pre-launch Features

3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).

3.4.2 The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.

3.4.3 The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.

3.5 Power

3.5.1 The satellite shall produce electrical power from sunlight.

3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.

3.5.3 The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.

3.5.4 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.

3.6 Experiment

- 3.6.1 The satellite shall provide DC power for experiment payloads.
- 3.6.2 The satellite shall provide a means to activate and deactivate the experiment payloads.
- 3.6.3 The satellite shall provide a means to telemeter data from the experiment payloads.

Note that the experiment payloads will be specified in a separate documents.

3.7 RF Uplink

- 3.7.1 The satellite shall include an FM uplink receiver.
- 3.7.2 The receiver shall have specifications as shown in Table 1.

Table 1

Sensitivity	-120 dBm for 12 dB SINAD (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz
Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ± 2.5 kHz (min.)

3.8 RF Downlink

- 3.8.1 The satellite shall include an FM downlink transmitter.
- 3.8.2 The transmitter shall have specifications as shown in Table 2.

Table 2

Power Output	400 mW (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz

3.8.3 The transmitter shall provide a means to prevent over modulation.

3.9 FM Transponder

3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.

3.9.2 In Transponder Mode, the IHU shall detect the presence of a 67 Hz CTCSS tone on the uplink.

3.9.3 In Transponder Mode, the downlink transmitter shall be keyed (*i.e. PTT-on*) by the IHU for 2 minutes following detection of the 67 Hz CTCSS tone.

3.9.4 In Transponder Mode, the downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once every 2 minutes on the uplink.

3.9.5 In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.

3.9.6 In Transponder Mode, if the downlink transmitter has been un-keyed for a period of 3 minutes, the satellite shall send "HI THIS IS AMSAT FOX" as a voice announcement on the downlink transmitter.

3.9.7 In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.

3.10 Telemetry Data

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include at a minimum, measured parameters as shown in Table 3.

Table 3

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
TX T	Temperature of RF transmitter card
RX T	Temperature of RF receiver card

- 3.10.3 The measured parameters shall be sampled at least every 15 seconds.
- 3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.
- 3.10.5 The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4.

Table 4

Parameter Name	Description
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

- 3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.

Note that the telemetry interface will be specified in a separate document.

3.11 Telemetry Transmission

- 3.11.1 The satellite shall send slow speed telemetry using FSK on the RF downlink.
- 3.11.2 The FSK shall use the frequency spectrum below the audible range.
- 3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.
- 3.11.4 The telemetry transmission shall include telemetry frames.
- 3.11.5 The telemetry transmission shall include experiment data.

3.12 Command Capability

- 3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.
- 3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.
- 3.12.3 The following commands shall be provided, as shown in Table 5.

Table 5

Command	Operation
TEST	Send test message
INHIBIT	Inhibit RF transmission
IHU OFF	Power off IHU & PSU
IHU ON	Power on IHU & PSU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
DATA MODE	Enter Data Mode

- 3.12.4 A TEST command shall cause the satellite to respond by sending a voice announcement on the RF downlink.
- 3.12.5 An INHIBIT command shall cause the satellite to cease RF transmissions.
- 3.12.6 An IHU OFF command shall cause the IHU and PSU Systems to power off.
- 3.12.7 An IHU ON command shall cause the IHU and PSU Systems to power on.
- 3.12.8 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.
- 3.12.9 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.
- 3.12.10 A DATA MODE command shall cause the satellite to enter the Data Mode.

Note that the control interface will be specified in a separate document.

3.13 On-Orbit Operating Modes

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Table 6

Name	Description
Startup Mode	Wait 45 minutes and deploy antennas
Transponder Mode	FM transponder; PTT and low speed telemetry via IHU
Data Mode	FM transmitter; PTT and high speed telemetry via IHU

3.13.2 The satellite shall transition between modes as shown in Figure 1.

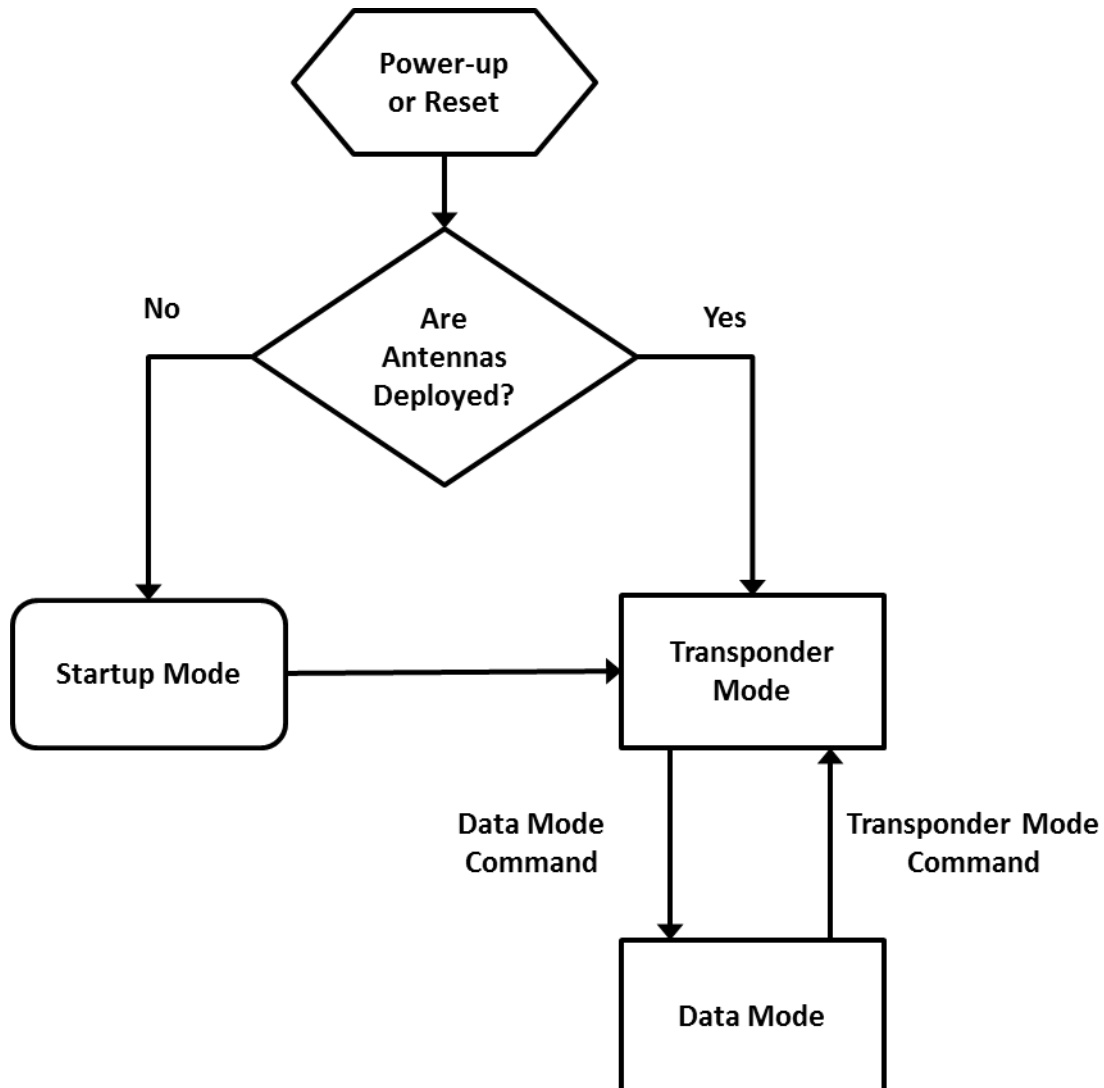


Figure 1. On-Orbit Operating Modes

- 3.13.3 Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.
- 3.13.4 An IHU ON Command shall cause the satellite to begin operation from the "Power-up" state as shown in Figure 1.
- 3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.
- 3.13.6 If the antennas have not been deployed, the satellite shall enter the Startup Mode.
- 3.13.7 In Startup Mode, the satellite shall wait 45 minutes, deploy the antennas, and then enter Transponder Mode.
 - 3.13.7.1 During the 45 minute wait the IHU shall flash a red LED.
 - 3.13.7.2 During the 45 minute wait the IHU shall sound a 1 kHz beeping tone.
- 3.13.8 In Transponder Mode, the transponder and the slow speed telemetry shall be active.
- 3.13.9 In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. *(i.e. signals that appear on the uplink shall not be repeated on the downlink.)*
- 3.13.10 If another Data Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Data Mode.
- 3.13.11 The RF uplink shall be monitored for commands in all modes.

4 External Interface Documents

To fully specify the satellite technical requirements, the following documents must also be provided;

1. IARU Coordinated Frequency Plan
2. Downlink Specification
3. Control Interface Specification
4. Experiment Payload Specifications

5 Summary

The *Fox-1* satellite will be AMSAT's first CubeSat. Its primary mission is to provide an FM Transponder communications capability. The secondary mission is to host a university-provided experiment payload.



Date: October 4, 2013

Version: 3.82

AMSAT Fox-1

Avionics System Design Specification

1 Introduction

This document contains the system level design specifications for the AMSAT Fox-1 satellite avionics systems. It is driven by the System Requirements Specification and other documents provided by the developers of the individual systems that make up the satellite system.

1.1. Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	From Draft F
April 9, 2012	1.1	Add signal characteristics, update bus pin connections per System Team input
April 17, 2012	1.2	Add external connector specification in sections 2.6, 2.12 and 2.14 and references in section 6
April 18, 2012	1.21	Add MMCX connectors gender
April 22, 2012	1.3	Minor corrections in signal characteristics, remove +Z antenna deploy and sensor connections
July 10, 2012	2.0	Many revisions from PDR
July 11, 2012	2.01	One RBF pin removed from bus pin assignments, updated 2.1 interconnect diagram, updated 2.1 signal characteristics
July 21, 2012	2.1	Revised bus signals, bus pin assignments Updated RF block diagram
July 22, 2012	2.11	Revision to some RF signal descriptions, change antenna/coax connectors to UMCC type, updated RF block diagram, added driving and load system columns to signal characteristics
September 9, 2012	3.0	Major changes.
September 11, 2012	3.01	Defunct IHU block diagram pending update
September 12, 2012	3.1	Added PCB volume requirements
September 23, 2012	3.11	Change TX PTT to RX PTT, -Z Deploy switches to TX, update figures and tables accordingly
September 26, 2012	3.12	Update bus and pin assignment drawings
September 27, 2012	3.13	Update bus pin assignment drawings
September 30, 2012	3.14	Update RF block diagram to remove ITAR notice
October 17, 2012	3.15	Import changes to requirements from System Requirements
February 17, 2013	3.2	Incorporate system bus signal nomenclature and pin assignment changes
February 28, 2013	3.3	MEC connector changed orientation (flipped) on +X -X +Y -Y panels.

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DATE	VERSION	SUMMARY
March 28, 2013	3.4	Add second –Z PPOD deploy switch (pin 54), PPOD deploy switches now on TX system card
March 31, 2013	3.41	Updates to the TX, RX, IHU, and BUS pin diagrams.
March 31, 2013	3.42	Adjusted RESERVED pin colors only
April 21, 2013	3.43	Addition of RX Frequency Control, TX Frequency Control, and Sensor Power signals Pin reassignments: Moved pins 52 and 54 to pins 33 and 35 respectively Moved pins 40 and 42 to pins 29 and 42 respectively Added the above new signals to pins 42, 40, and 38 respectively
April 25, 2013	3.5	Update per System Requirements 3.10.2 changes. Updated bus connection pin assignments, bus interconnect diagram, and system bus signal characteristics account removal of TX OSC Temp and TX PA Temp and addition of TX Temperature
June 26, 2013	3.6	Add requirements for PSU and BATT1 CPU reset from RX Command Data, updated IHU block diagram
July 24, 2013	3.7	Add ALERT signal, SENSOR POWER signal, remove RBF2, rename RBF1 to Solar Safe N, remove RX Command Data connection from BATT1, flip MEC connector orientation on +X, -X, +Y, -Y panels, update ME-113 mechanical drawings
August 26, 2013	3.8	Rename RX OSC TEMP to RX Temperature, add Initial Surge Current Limits for certain systems, move Command Decoder to IHU system (bus pin changes), update some bus nomenclature, update System Requirements for each system per changes to the System Requirements
August 27, 2013	3.81	Correct source and destination for RX Command Strobe in Table 1
September 17, 2013	3.82	Add (move) RSSI to Pin 10, rename Pin 32 as RX CD, add Solar Power A and Solar Power B to pins 55 and 56, update TX Block Diagram, remove RX Command Data connection from PSU, update hyperlinks.

1.2. Document Scope

The purpose of this document is to specify the avionics systems and their connections to each other and to external components for the satellite. It is intended to be used by the hardware, software, and mechanical designers to develop the architecture and interconnections for the satellite avionics systems.

1.3. Document Format

This document provides these elements in a numbered format. The numbered sections specify each major system in the satellite while numbered items for each system specify the external connections required and the number of lines for each connection. Satellite bus and external connections are further described in figures and tables.

Where System Requirements are reproduced their numbers are from the AMSAT Fox-1 System Requirements Specification.

1.4. References

1. AMSAT Fox-1 ConOps
2. AMSAT Fox-1 System Requirements Specification
3. AMSAT Fox-1 Bus (Signal Connections Diagram)
4. AMSAT Fox-1 Bus Pin Assignment
5. AMSAT Fox-1 Avionics System Design Specification Spreadsheet
6. AMSAT FOX-ME-120_Z_TOPBOTT_SOLAR_PANEL.pdf
7. AMSAT FOX-ME-127_Y_SIDE_SOLAR_PANEL.pdf



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AMSAT Fox-1 Avionics System Design Specification



2 Avionics System Bus Signals, Characteristics, and Connections

October 4, 2013
Version 1.93

FOX-1 Signal Connections Diagram

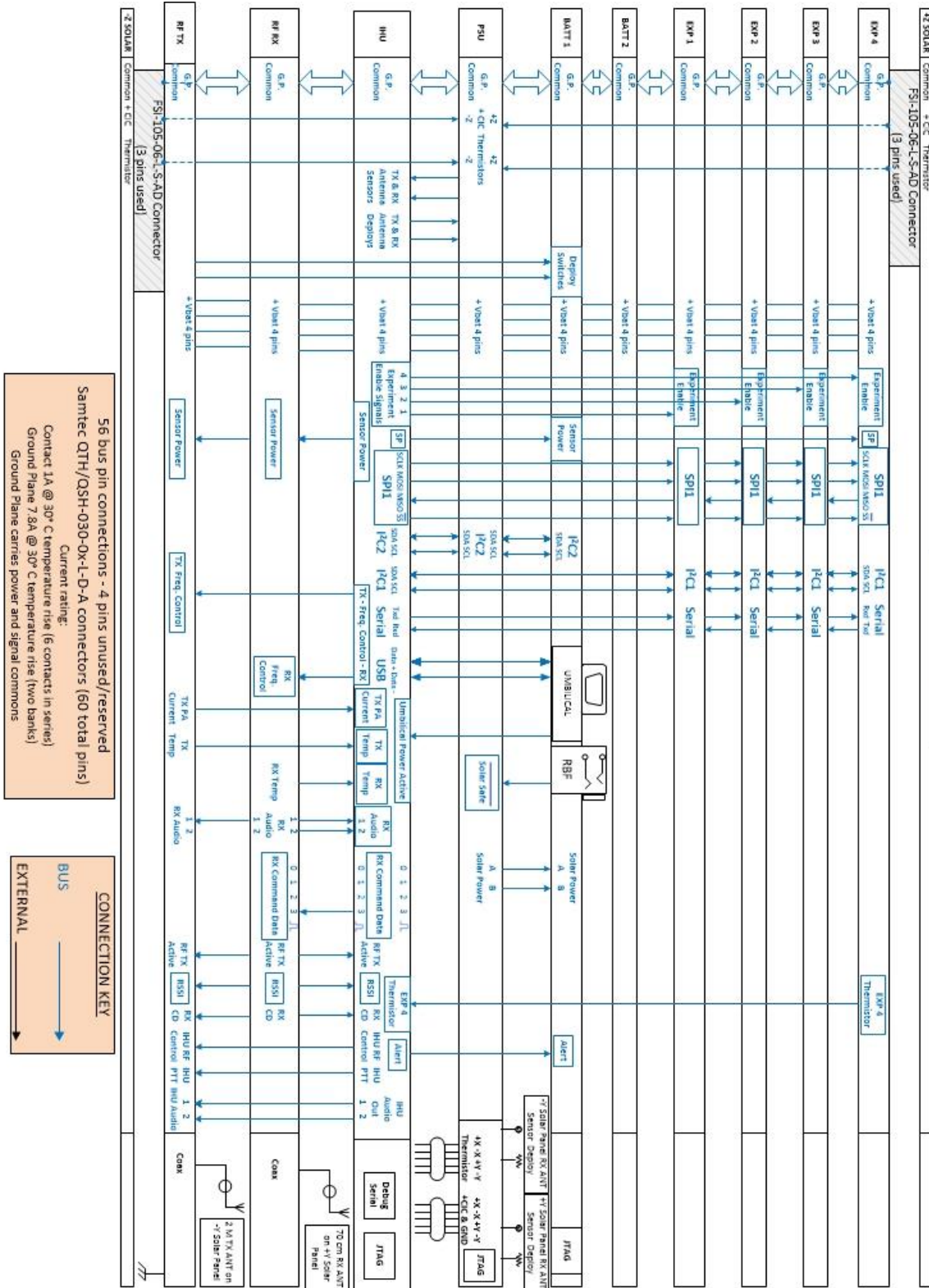


Figure 1: Interconnect Diagram

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Avionics System Design Specification



Table 1: System Bus Signal Characteristics

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
1	SPI1 NSS	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	
3	SPI1 SCK	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
4	TX Temperature	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	Thermistor Circuit
5	SPI1 MISO	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
6	Experiment 4 Thermistor	Analog	N/A	EXP 4	N/A	IHU	Temperature from Experiment 4 position
7	SPI1 MOSI	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
8	RX Temperature	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Thermistor Circuit
9	Serial RXD	Digital	3.0 V	EXP 1-4		IHU	Async, Mark High
10	RSSI	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Received Signal Strength Indication
11	Serial TXD	Digital	3.0 V	IHU		EXP 1-4	Async, Mark High
12	IHU Audio 1 Out	Analog	0 - 3 V (audio)	IHU	> 10 kΩ unbal.	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
13	Experiment Enable 1	Digital		IHU		EXP 1-4	HIGH = Enable EXP 1
14	IHU Audio 2 Out	Analog	0 - 3 V (audio)	IHU	> 10 kΩ unbal.		IHU Audio 2 Out Not Used on Fox-1A
15	Experiment Enable 2	Digital		IHU		EXP 2	HIGH = Enable EXP 2
16	RX Command Data 0	Digital		IHU			(Least Significant Bit) Not Used on Fox-1A
17	Experiment Enable 3	Digital		IHU		EXP 3	HIGH = Enable EXP 3
18	RX Command Data 1	Digital		IHU			Not Used on Fox-1A
19	Experiment Enable 4	Digital		IHU		EXP 4	HIGH = Enable EXP 4
20	RX Command Data 2	Digital		IHU			HIGH = IHU off
21	Not Used						
22	RX Command Data 3	Digital		IHU		TX	(Most Significant Bit) HIGH = Inhibit Transmit
23	I ² C1 SCL	Digital	Note ¹	IHU			I ² C Standard, IHU Master
24	RX Command Strobe	Digital		IHU			HIGH = Command Data change
25	I ² C1 SDA	Digital	Note ¹	IHU			I ² C Standard, IHU Master
26	IHU RF Control	Digital		IHU		TX	HIGH = IHU Controls RF LOW = Standalone Analog Transponder
27	Not Used						
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT
29	Solar Safe N	Switch	N/A	BATT	N/A	PSU	N.O. for operation
30	RF TX Active	Digital		TX		IHU	HIGH = RF TX on
31	Alert Signal	Digital		IHU		BATT	
32	RX CD	Digital		RX		TX IHU	HIGH = valid receive signal
33	-Z Deploy Switch 1	Switch	N/A	TX	N/A	PSU/BATT	N.O. when deployed
34	RX Audio 1	Analog	0 - 3 V (audio)	RX	> 10 kΩ unbal.	IHU	10 Hz - 7 kHz bandwidth
35	-Z Deploy Switch 2	Switch	N/A	TX	N/A	PSU/BATT	N.O. when deployed
36	RX Audio 2	Analog	0 - 3 V (audio)		> 10 kΩ unbal.	IHU	RX Audio 2 Not Used on Fox-1A
37	I ² C2 SCL	Digital	Note ¹	IHU		PSU/BATT	I ² C Standard, IHU Master
38	Sensor Power	Analog	+3 VDC	IHU		TX RX BATT EXP4	Power for analog telemetry sensors
39	I ² C2 SDA	Digital	Note ¹	IHU		PSU/BATT	I ² C Standard, IHU Master
40	TX Frequency Control	Digital		IHU		TX	Not Used on Fox-1A
41	+Z Thermistor	Analog	N/A	EXP 4	N/A	PSU	
42	RX Frequency Control	Digital		IHU		RX	Not Used on Fox-1A
43	-Z Thermistor	Analog	N/A	TX	N/A	PSU	
44	-Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	PSU	
45	+Z CIC	Power	N/A	EXP 4	N/A	PSU	
46	-Y Antenna Sensor	Switch	N/A	PSU	N.O.	IHU	N.O. when deployed
47	-Z CIC	Power	N/A	TX	N/A	PSU	
48	+Y Antenna Sensor	Switch	N/A	PSU	N.O.	IHU	N.O. when deployed
49	Umbilical USBP	Digital		BATT		IHU	USB Standard
50	+Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	PSU	
51	Umbilical USBM	Digital		BATT		IHU	USB Standard
52	Not Used						
53	Umbilical Power Active	Digital		BATT		IHU	HIGH = Running on Umbilical Port Power
54	*RESERVED*						Must not use on v1 IHU Card
55	Solar Power A	Power	Vbatt	PSU		BATT	
56	Solar Power B	Power	Vbatt	PSU		BATT	
57	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
58	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
59	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
60	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	

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Note¹ All SPI and I²C signals are 3.0 V levels

All Digital signals are CMOS logic levels high impedance load unless otherwise noted

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Avionics System Design Specification



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Note¹ All SPI and I²C signals are 3.0 V levels All Digital signals are 3.0 V CMOS logic levels high impedance load unless otherwise noted

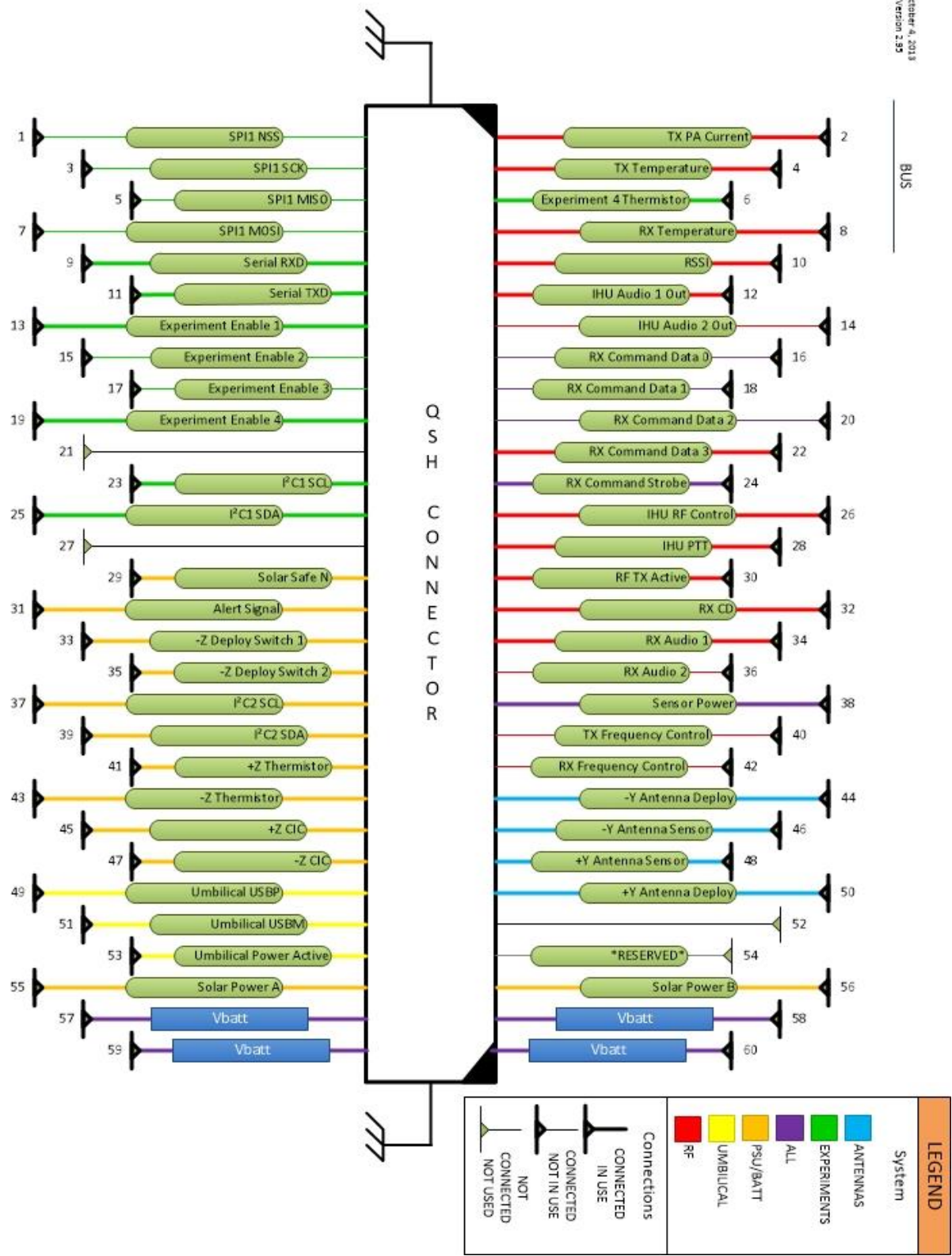


Figure 2: Complete Bus Connection Pin Assignments

3 RF Transmitter System

3.1 System Requirements Applicable to RF Transmitter System

2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.		
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.		
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.		
2.4.1	All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.		
2.4.3	All satellite downlinks shall be in the 2 meter band within the amateur satellite service.		
2.4.4	All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.		
2.4.5	All satellite frequencies shall be coordinated with the IARU.		
3.8.1	The satellite shall include an FM downlink transmitter.		
3.8.2	The transmitter shall have specifications as shown in Table 2.		
		Power Output	400 mW (min.)
		FM Deviation	5 kHz
		Audio Bandwidth	3 kHz
3.8.3	The transmitter shall provide a means to prevent over modulation.		
3.9.1	The satellite shall provide an FM transponder via the RF uplink and RF downlink.		
3.9.3	In Transponder Mode, the downlink transmitter shall be keyed (i.e. PTT-on) by the IHU for 2 minutes following detection of the 67 Hz CTCSS tone.		
3.9.5	In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.		
3.9.7	In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.		
3.10.1	The satellite shall collect telemetry data.		
3.10.2	The telemetry data shall include at a minimum, measured parameters as shown in Table 3.		
		Parameter Name	Description
		CELL V	Voltages of battery cells
		PANEL V	Voltages of solar panels
		TOTAL I	Total DC current out of power system
		PA I	DC current into RF power amp
		BATTERY T	Temperature of battery
		PANEL T	Temperatures of solar panels
		TX T	Temperature of RF transmitter card

		RX T	Temperature of RF receiver card	
3.10.3	The measured parameters shall be sampled at least every 15 seconds.			
3.11.1	The satellite shall send slow speed telemetry using FSK on the RF downlink.			
3.11.2	The FSK shall use the frequency spectrum below the audible range.			
3.11.3	The telemetry shall be transmitted simultaneously with any transponder communications.			
3.12.1	The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.			
3.12.2	The commands received via the RF uplink shall not be repeated on the RF downlink.			
3.12.3	The following commands shall be provided, as shown in Table 5.			
		Command	Operation	
		TEST	Send test message	
		INHIBIT	Inhibit RF transmission	
		IHU OFF	Power off IHU	
		IHU ON	Power on IHU	
		CLEAR	Clear stored telemetry	
		TRANSPONDER MODE	Enter Transponder Mode	
		DATA MODE	Enter Data Mode	
3.12.4	A TEST command shall cause the satellite to respond by sending a voice announcement on the RF downlink.			
3.12.5	An INHIBIT command shall cause the satellite to cease RF transmissions.			
3.12.9	A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.			
3.12.10	A DATA MODE command shall cause the satellite to enter the Data Mode.			
3.13.1	The satellite shall provide on-orbit operating modes as shown in Table 6.			
		Name	Description	
		Startup Mode	Wait 45 minutes and deploy antennas	
		Transponder Mode	FM transponder; PTT and low speed telemetry via IHU	
		Data Mode	FM transmitter; PTT and high speed telemetry via IHU	
3.13.5	If the antennas have been deployed, the satellite shall enter the Transponder Mode.			
3.13.8	In Transponder Mode, the transponder and the slow speed telemetry shall be active.			
3.13.9	In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)			



3.2 Initial Surge Current Limits

3.2.1 The RF Transmitter design shall limit initial inrush current to 2.5 Amperes.

3.3 Volume Requirements Applicable to RF Transmitter System

3.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5 mm from the -Z surface of the PC board.

3.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

3.4 Interface Control Documents Applicable to RF Transmitter System

[AMSAT Fox-1 IHU to RF System Interface Control Document](#)

3.5 RF Transmitter System PCB Bus Connections

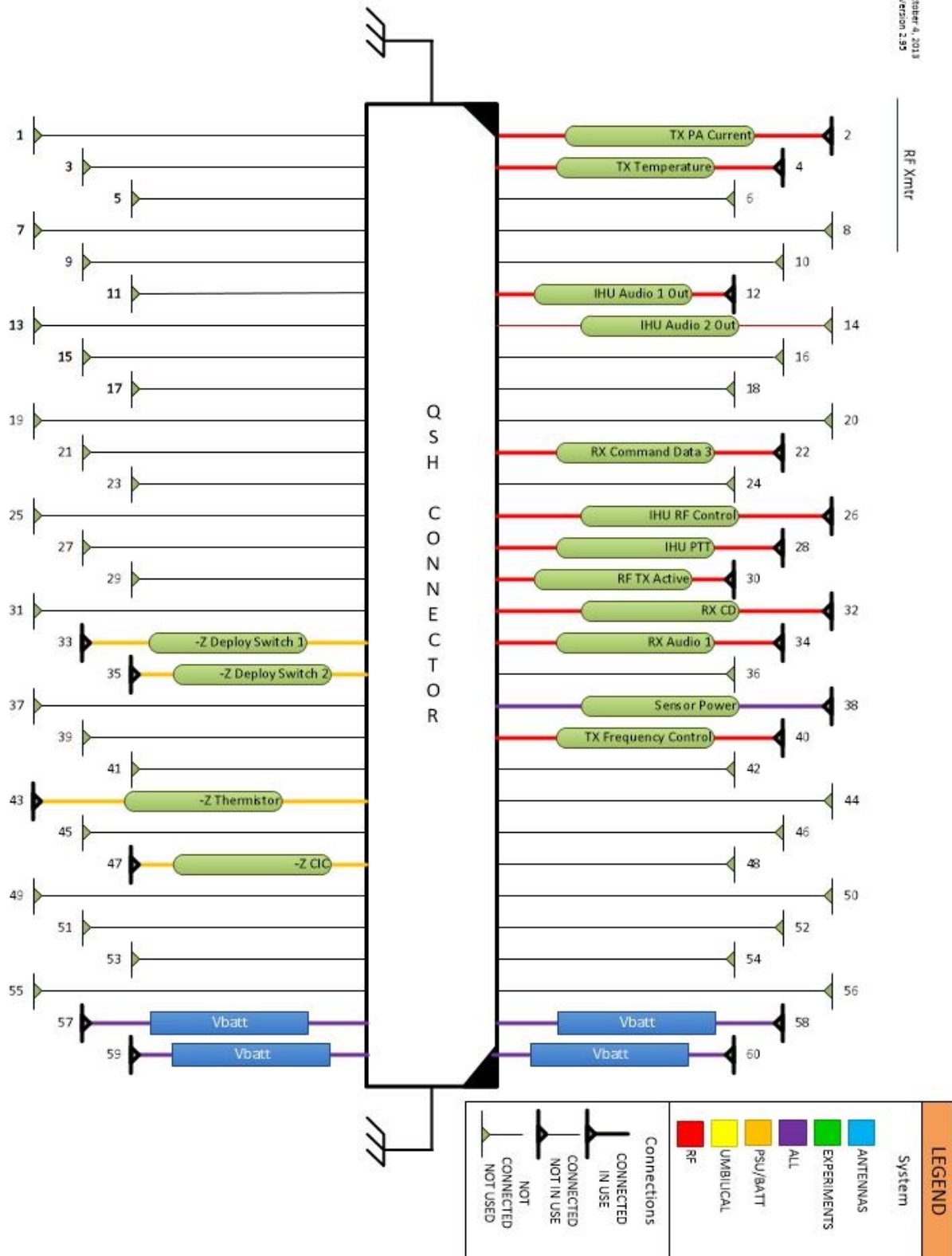


Figure 3: RF Transmitter System Bus Connection Pin Assignments

3.6 RF Transmitter System PCB External Connections

3.6.1 2 meter band RF output, coaxial cable to Transmit Antenna

3.6.2 Spacecraft deployment switches cable(s) TBR

3.6.3 Three connections via Samtec FSI-105-06-L-S-AD connector

3.6.3.1 1 contact -Z Solar Panel Thermistor

3.6.3.2 1 contact -Z Solar Panel CIC +

3.6.3.3 1 contact common or - for above four connections

Table 2: External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	2 meter Antenna $\approx$ 145.9 MHz	RF	0 to +30 dBm	2 meter Antenna	50 Ω unbal.	N/A

Table 3: -Z PCB face FSI-105-06-L-S-AD connector mates to pads on -Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	-Z Thermistor	Analog	N/A	N/A	N/A	PSU	43
2	N/C						
3	-Z Solar Panel Common						Ground Plane
4	N/C						
5	-Z CIC	Power	N/A	N/A	N/A	PSU	47

July 24, 2013
Version 1.3

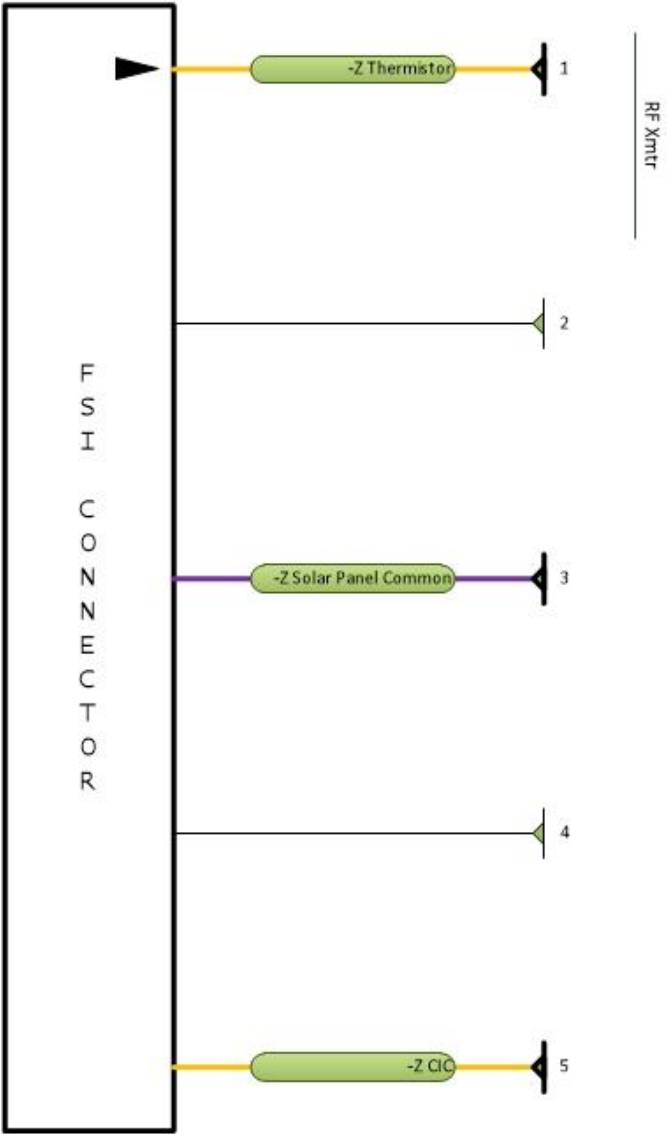


Figure 4: RF Transmitter System FSI-105-06-L-S-AD Connection Pin Assignments

4 RF Receiver System

4.1 System Requirements Applicable to RF Receiver System

2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.	
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.	
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.	
2.4.2	All satellite uplinks shall be in the 70 cm band of the amateur satellite service.	
2.4.5	All satellite frequencies shall be coordinated with the IARU.	
3.7.1	The satellite shall include an FM uplink receiver.	
3.7.2	The receiver shall have specifications as shown in Table 1.	
	Sensitivity	-120 dBm for 12 dB SINAD (min.)
	FM Deviation	5 kHz
	Audio Bandwidth	3 kHz
	Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ± 2.5 kHz (min.)
3.8.3	The transmitter shall provide a means to prevent over modulation.	
3.9.1	The satellite shall provide an FM transponder via the RF uplink and RF downlink.	
3.9.7	In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.	
3.10.1	The satellite shall collect telemetry data.	
3.10.2	The telemetry data shall include at a minimum, measured parameters as shown in Table 3.	
	Parameter Name	Description
	CELL V	Voltages of battery cells
	PANEL V	Voltages of solar panels
	TOTAL I	Total DC current out of power system
	PA I	DC current into RF power amp
	BATTERY T	Temperature of battery
	PANEL T	Temperatures of solar panels
	TX T	Temperature of RF transmitter card
	RX T	Temperature of RF receiver card
3.10.3	The measured parameters shall be sampled at least every 15 seconds.	
3.12.2	The commands received via the RF uplink shall not be repeated on the RF downlink.	
3.13.11	The RF uplink shall be monitored for commands in all modes.	



4.2 Initial Surge Current Limits

4.2.1 The RF Receiver design shall limit initial inrush current to 0.1 Amperes.

4.3 Volume Requirements Applicable to RF Receiver System

4.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

4.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

4.4 Interface Control Documents Applicable to RF Receiver System

[AMSAT Fox-1 IHU to RF System Interface Control Document](#)

4.5 RF Receiver System PCB Bus Connections

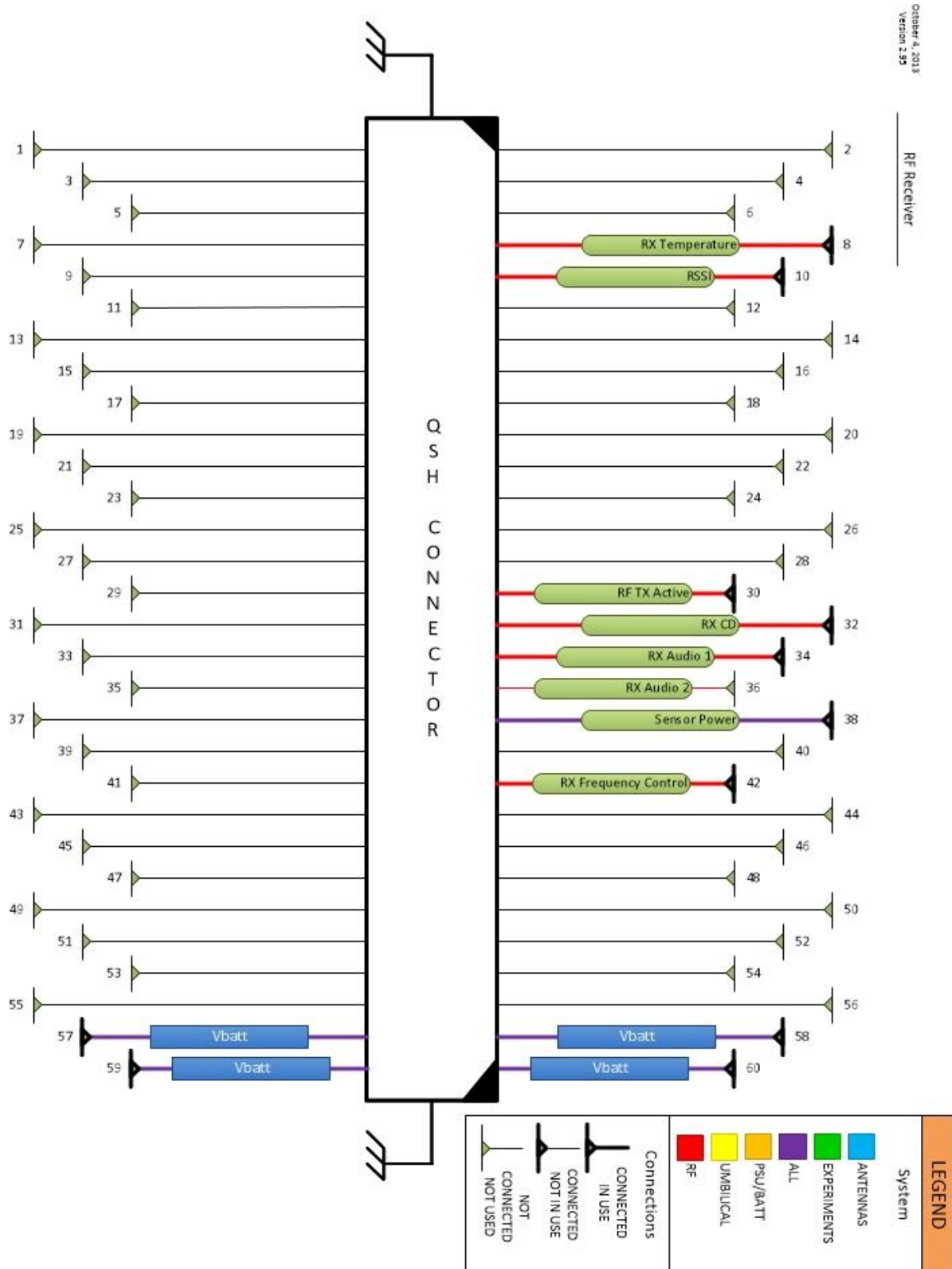


Figure 5: RF Receiver System Bus Connection Pin Assignments

4.6 RF Receiver System PCB External Connections

4.6.1 70cm band RF input, coaxial cable to Receive Antenna

Table 4: RF Receiver System External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	70 cm RF Input 437 MHz	RF	-60 dBm to -140 dBm	70 cm Antenna	50 Ω unbal.	N/A

5 Internal Housekeeping Unit (IHU) System

5.1 System Requirements Applicable to Internal Housekeeping Unit (IHU) System

2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.																		
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.																		
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.																		
3.3.2	The satellite shall include an umbilical port as per the CubeSat Design Specification.																		
3.4.3	The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.																		
3.6.2	The satellite shall provide a means to activate and deactivate the experiment payloads.																		
3.6.3	The satellite shall provide a means to telemeter data from the experiment payloads.																		
3.9.2	In Transponder Mode, the IHU shall detect the presence of a 67 Hz CTCSS tone on the uplink.																		
3.9.3	In Transponder Mode, the downlink transmitter shall be keyed (i.e. PTT-on) by the IHU for 2 minutes following detection of the 67 Hz CTCSS tone.																		
3.9.4	In Transponder Mode, the downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once every 2 minutes on the uplink.																		
3.9.5	In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.																		
3.9.6	In Transponder Mode, if the downlink transmitter has been un-keyed for a period of 3 minutes, the satellite shall send "HI THIS IS AMSAT FOX" as a voice announcement on the downlink transmitter.																		
3.9.7	In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.																		
3.10.1	The satellite shall collect telemetry data.																		
3.10.2	The telemetry data shall include at a minimum, measured parameters as shown in Table 3. <table border="1"> <thead> <tr> <th>Parameter Name</th><th>Description</th></tr> </thead> <tbody> <tr> <td>CELL V</td><td>Voltages of battery cells</td></tr> <tr> <td>PANEL V</td><td>Voltages of solar panels</td></tr> <tr> <td>TOTAL I</td><td>Total DC current out of power system</td></tr> <tr> <td>PA I</td><td>DC current into RF power amp</td></tr> <tr> <td>BATTERY T</td><td>Temperature of battery</td></tr> <tr> <td>PANEL T</td><td>Temperatures of solar panels</td></tr> <tr> <td>TX T</td><td>Temperature of RF transmitter card</td></tr> <tr> <td>RX T</td><td>Temperature of RF receiver card</td></tr> </tbody> </table>	Parameter Name	Description	CELL V	Voltages of battery cells	PANEL V	Voltages of solar panels	TOTAL I	Total DC current out of power system	PA I	DC current into RF power amp	BATTERY T	Temperature of battery	PANEL T	Temperatures of solar panels	TX T	Temperature of RF transmitter card	RX T	Temperature of RF receiver card
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BATTERY T	Temperature of battery																		
PANEL T	Temperatures of solar panels																		
TX T	Temperature of RF transmitter card																		
RX T	Temperature of RF receiver card																		
3.10.3	The measured parameters shall be sampled at least every 15 seconds.																		
3.10.4	The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.																		

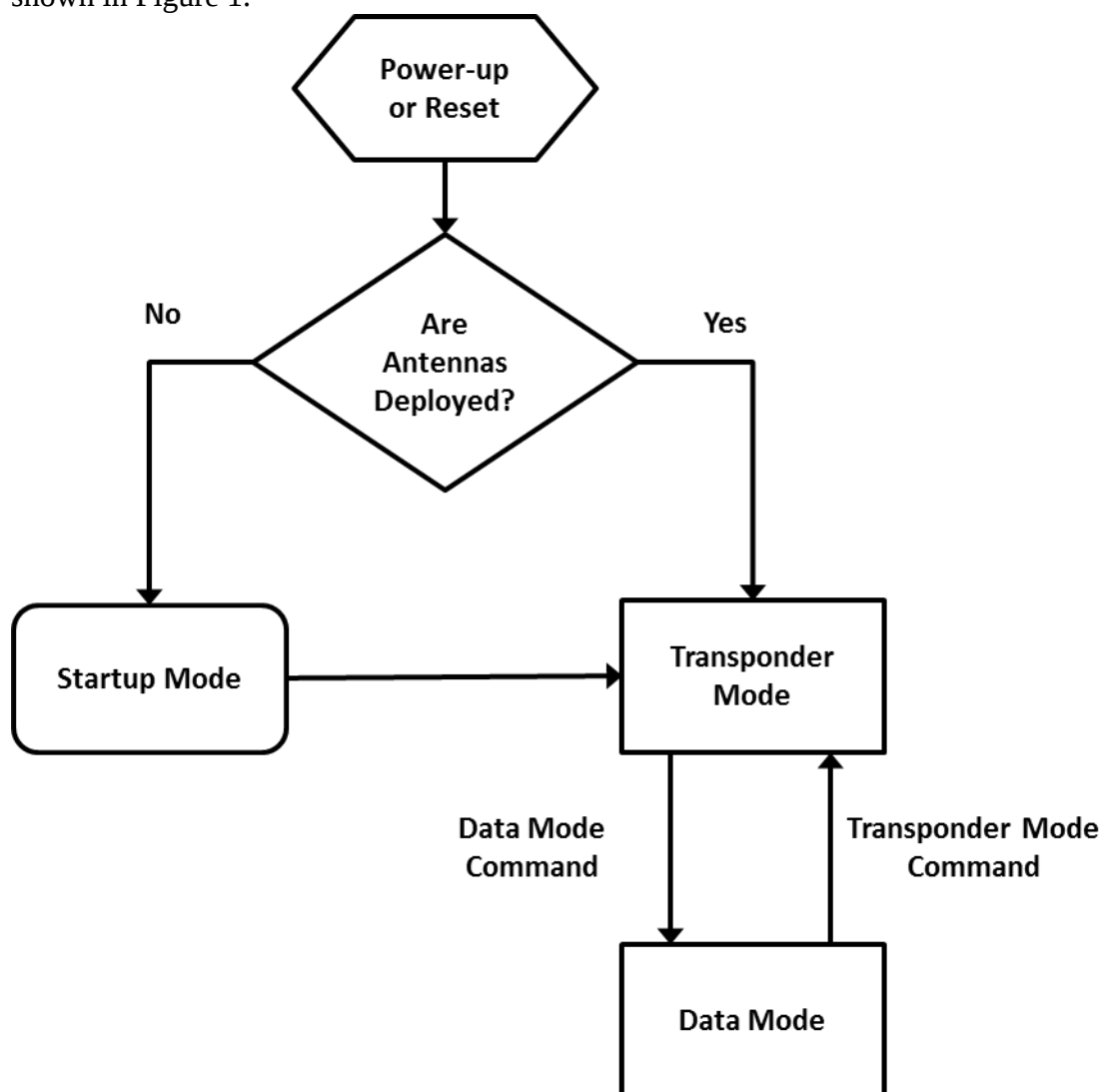
3.10.5	The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4.	
	Parameter Name	Description
	UP TIME	Total seconds since avionics power-up or reset
	SPIN	Satellite spin rate and direction
3.10.6	A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.	
3.11.1	The satellite shall send slow speed telemetry using FSK on the RF downlink.	
3.11.2	The FSK shall use the frequency spectrum below the audible range.	
3.11.3	The telemetry shall be transmitted simultaneously with any transponder communications.	
3.11.4	The telemetry transmission shall include telemetry frames.	
3.11.5	The telemetry transmission shall include experiment data.	
3.12.1	The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.	
3.12.3	The following commands shall be provided, as shown in Table 5.	
	Command	Operation
	TEST	Send test message
	INHIBIT	Inhibit RF transmission
	IHU OFF	Power off IHU
	IHU ON	Power on IHU
	CLEAR	Clear stored telemetry
	TRANSPONDER MODE	Enter Transponder Mode
	DATA MODE	Enter Data Mode
3.12.4	A TEST command shall cause the satellite to respond by sending a voice announcement on the RF downlink.	
3.12.6	An IHU OFF command shall cause the IHU System to power off.	
3.12.7	An IHU ON command shall cause the IHU System to power on.	
3.12.8	A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.	
3.12.9	A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.	
3.12.10	A DATA MODE command shall cause the satellite to enter the Data Mode.	
3.13.1	The satellite shall provide on-orbit operating modes as shown in Table 6.	
	Name	Description
	Startup Mode	Wait 45 minutes and deploy antennas

		Transponder Mode	FM transponder; PTT and low speed telemetry via IHU	
		Data Mode	FM transmitter; PTT and high speed telemetry via IHU	

3.13.2 The satellite shall transition between modes as shown in Figure 1.

3.13.3 Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.

3.13.4 An IHU ON Command shall cause the satellite to begin operation from the "Power-up" state as shown in Figure 1.



3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.

3.13.6 If the antennas have not been deployed, the satellite shall enter the Startup Mode.

3.13.7 In Startup Mode, the satellite shall wait 45 minutes, deploy the antennas, and then enter Transponder Mode.

3.13.8 In Transponder Mode, the transponder and the slow speed telemetry shall be active.

3.13.9 In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (i.e.

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	signals that appear on the uplink shall not be repeated on the downlink.)
3.13.10	If another Data Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Data Mode.
3.13.11	The RF uplink shall be monitored for commands in all modes.
3.13.7.1	During the 45 minute wait the IHU shall flash a red LED.
3.13.7.2	During the 45 minute wait the IHU shall sound a 1 kHz beeping tone.



5.3 Initial Surge Current Limits

5.3.1 The IHU design shall limit initial inrush current to 0.1 Amperes.

5.4 Volume Requirements Applicable to IHU System

5.4.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

5.4.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

5.5 Interface Control Documents Applicable to IHU System

[AMSAT Fox-1 IHU to RF System Interface Control Document](#)

[AMSAT Fox-1 IHU to PSU Interface Control Document](#)

[AMSAT Fox-1 IHU to Battery Interface Control Document](#)

[AMSAT Fox-1 IHU to Attitude Determination Experiment Interface Control Document](#)

[AMSAT Fox-1 IHU to Experiment 1 Interface Control Document](#)

[AMSAT Fox-1 IHU to Experiment 4 Interface Control Document](#)

5.6 Internal Housekeeping Unit (IHU) System PCB Bus Connections

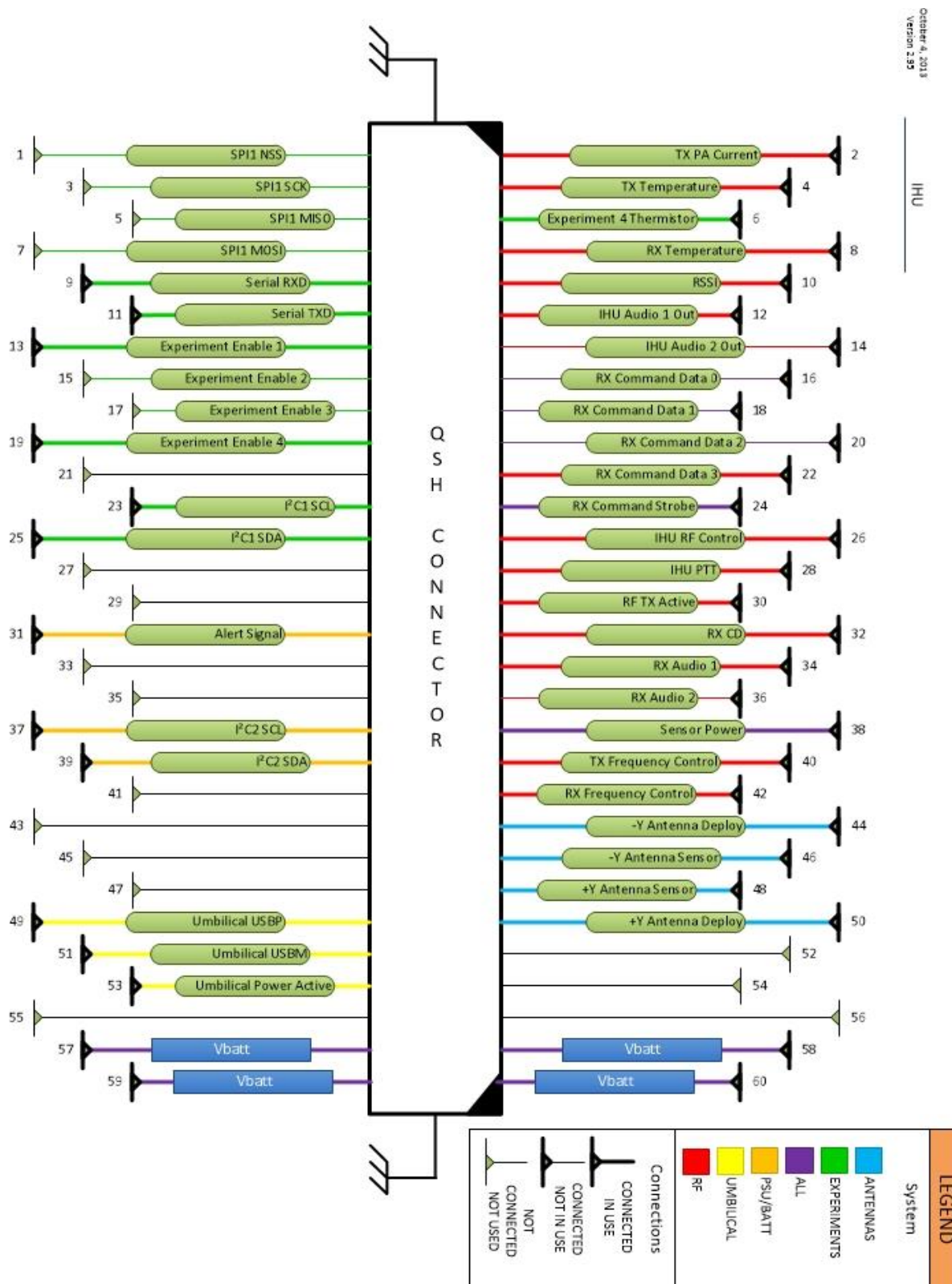


Figure 6: IHU System Bus Connection Pin Assignments

6 Power Supply System (PSU)

6.1 System Requirements Applicable to Power Supply System (PSU)

2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.																		
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.																		
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.																		
3.3.1	The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.																		
3.4.1	The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).																		
3.4.2	The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.																		
3.5.1	The satellite shall produce electrical power from sunlight.																		
3.5.2	The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.																		
3.5.3	The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.																		
3.5.4	The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.																		
3.6.1	The satellite shall provide DC power for experiment payloads.																		
3.10.1	The satellite shall collect telemetry data.																		
3.10.2	The telemetry data shall include at a minimum, measured parameters as shown in Table 3. <table border="1"> <thead> <tr> <th>Parameter Name</th><th>Description</th></tr> </thead> <tbody> <tr> <td>CELL V</td><td>Voltages of battery cells</td></tr> <tr> <td>PANEL V</td><td>Voltages of solar panels</td></tr> <tr> <td>TOTAL I</td><td>Total DC current out of power system</td></tr> <tr> <td>PA I</td><td>DC current into RF power amp</td></tr> <tr> <td>BATTERY T</td><td>Temperature of battery</td></tr> <tr> <td>PANEL T</td><td>Temperatures of solar panels</td></tr> <tr> <td>TX T</td><td>Temperature of RF transmitter card</td></tr> <tr> <td>RX T</td><td>Temperature of RF receiver card</td></tr> </tbody> </table>	Parameter Name	Description	CELL V	Voltages of battery cells	PANEL V	Voltages of solar panels	TOTAL I	Total DC current out of power system	PA I	DC current into RF power amp	BATTERY T	Temperature of battery	PANEL T	Temperatures of solar panels	TX T	Temperature of RF transmitter card	RX T	Temperature of RF receiver card
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BATTERY T	Temperature of battery																		
PANEL T	Temperatures of solar panels																		
TX T	Temperature of RF transmitter card																		
RX T	Temperature of RF receiver card																		
3.10.3	The measured parameters shall be sampled at least every 15 seconds.																		
3.10.5	The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4. <table border="1"> <thead> <tr> <th>Parameter Name</th><th>Description</th></tr> </thead> <tbody> </tbody> </table>	Parameter Name	Description																
Parameter Name	Description																		

		UP TIME	Total seconds since avionics power-up or reset	
		SPIN	Satellite spin rate and direction	
3.12.3	The following commands shall be provided, as shown in Table 5.			
		Command	Operation	
		TEST	Send test message	
		INHIBIT	Inhibit RF transmission	
		IHU OFF	Power off IHU & PSU	
		IHU ON	Power on IHU & PSU	
		CLEAR	Clear stored telemetry	
		TRANSPONDER MODE	Enter Transponder Mode	
		DATA MODE	Enter Data Mode	
3.13.7.1	During the 45 minute wait the IHU shall flash a red LED.			



6.2 Initial Surge Current Limits

6.2.1 The PSU design shall limit initial inrush current to 0.1 Amperes.

6.3 Volume Requirements Applicable to PSU System

6.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

6.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 3.0 mm from the +Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 6.0 mm from the +Z surface of the PC board in the rest of the board area.

6.4 Interface Control Documents Applicable to PSU System

[AMSAT Fox-1 IHU to PSU Interface Control Document](#)

6.5 Power Supply System (PSU) PCB Bus Connections

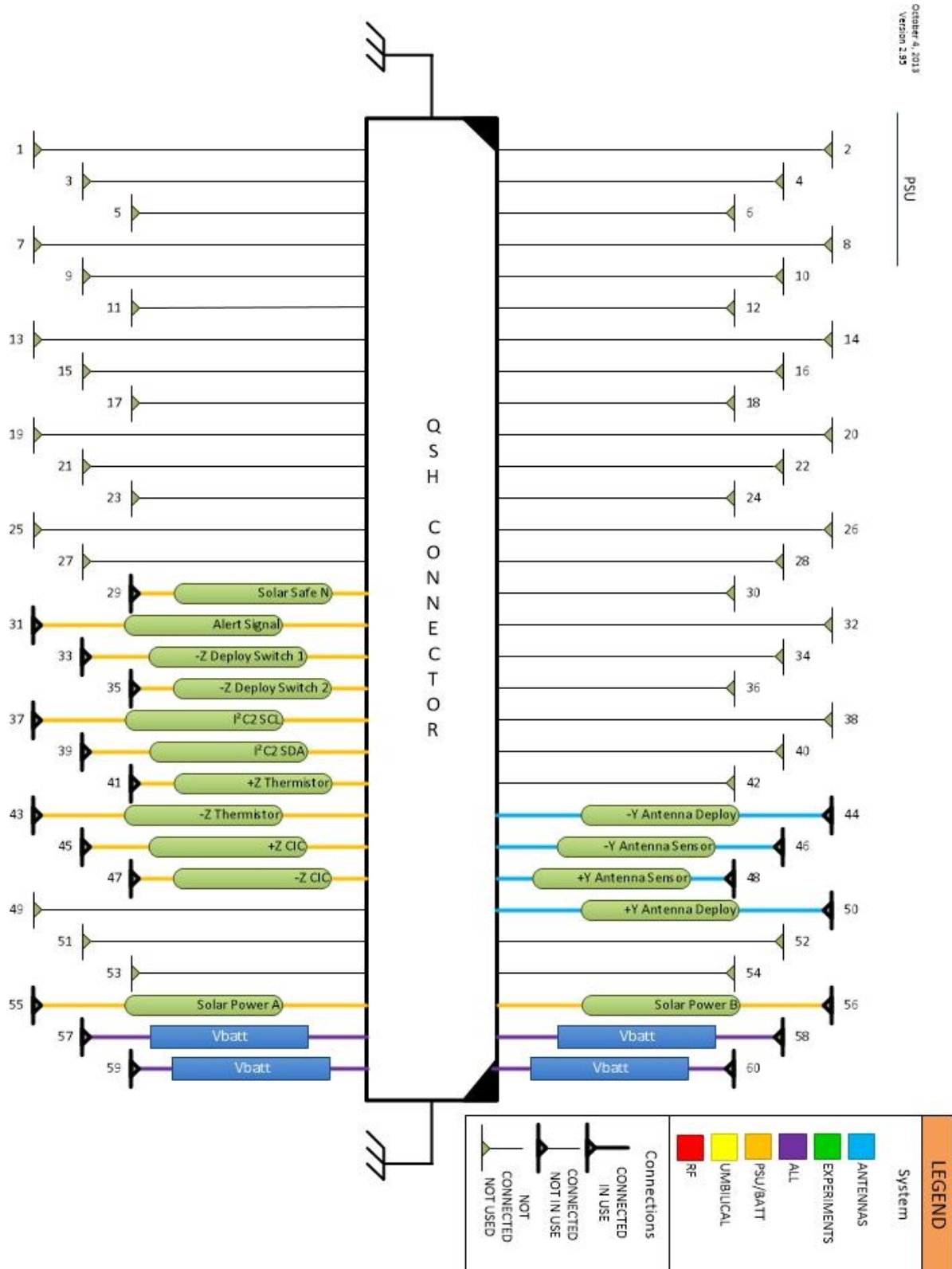


Figure 7: PSU Bus Connection Pin Assignments

6.6 Power Supply System (PSU) PCB External Connections

- 6.6.1** Three connections to +X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
 - 6.6.1.1** 1 contact +X Solar Panel Thermistor
 - 6.6.1.2** 1 contact +X Solar Panel CIC +
 - 6.6.1.3** 1 contact common or - for above two connections
- 6.6.2** Three connections to -X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
 - 6.6.2.1** 1 contact -X Solar Panel Thermistor
 - 6.6.2.2** 1 contact -X Solar Panel CIC +
 - 6.6.2.3** 1 contact common or - for above two connections
- 6.6.3** Five connections to +Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
 - 6.6.3.1** 1 contact +Y Solar Panel Thermistor
 - 6.6.3.2** 1 contact +Y Solar Panel CIC +
 - 6.6.3.3** 1 contact TX Antenna Deploy
 - 6.6.3.4** 1 contact TX Antenna Sensor
 - 6.6.3.5** 1 contact common or - for above connections
- 6.6.4** Five connections to -Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
 - 6.6.4.1** 1 contact -Y Solar Panel Thermistor
 - 6.6.4.2** 1 contact -Y Solar Panel CIC +
 - 6.6.4.3** 1 contact RX Antenna Deploy
 - 6.6.4.4** 1 contact RX Antenna Sensor
 - 6.6.4.5** 1 contact common or - for above connections
- 6.6.5** All PCB edges that connect to solar panel MEC1-105-02-L-D-NP-A connectors shall have contact pads on the PCB for all connector pins, whether connected to a trace or not.

Table 5: +X PCB edge mates to MEC1-105-02-L-D-NP-A connector on +X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	+X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	+X Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

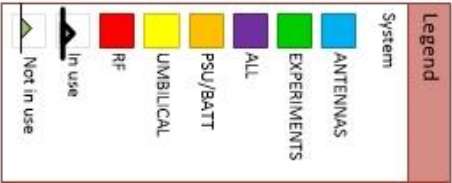
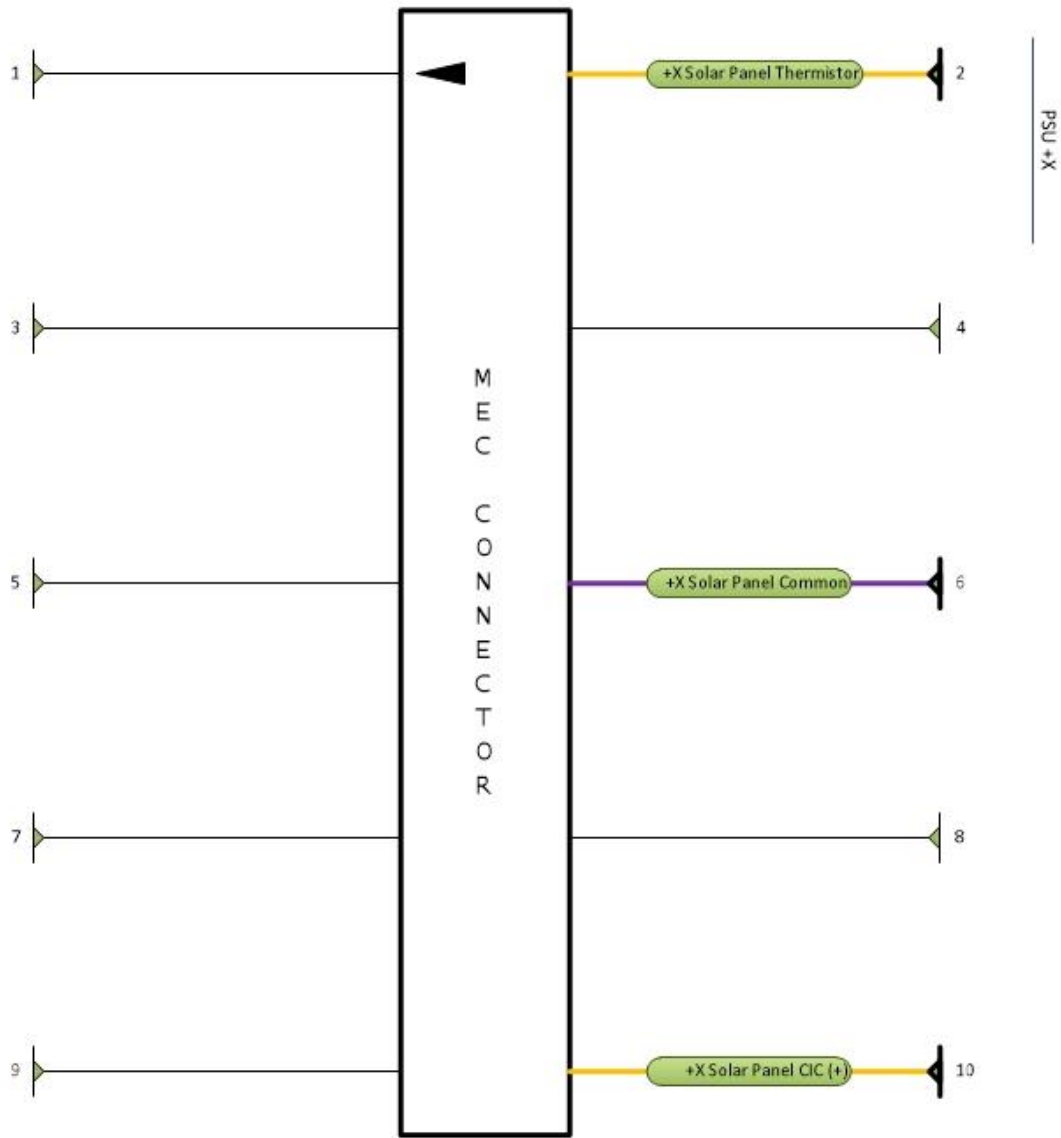


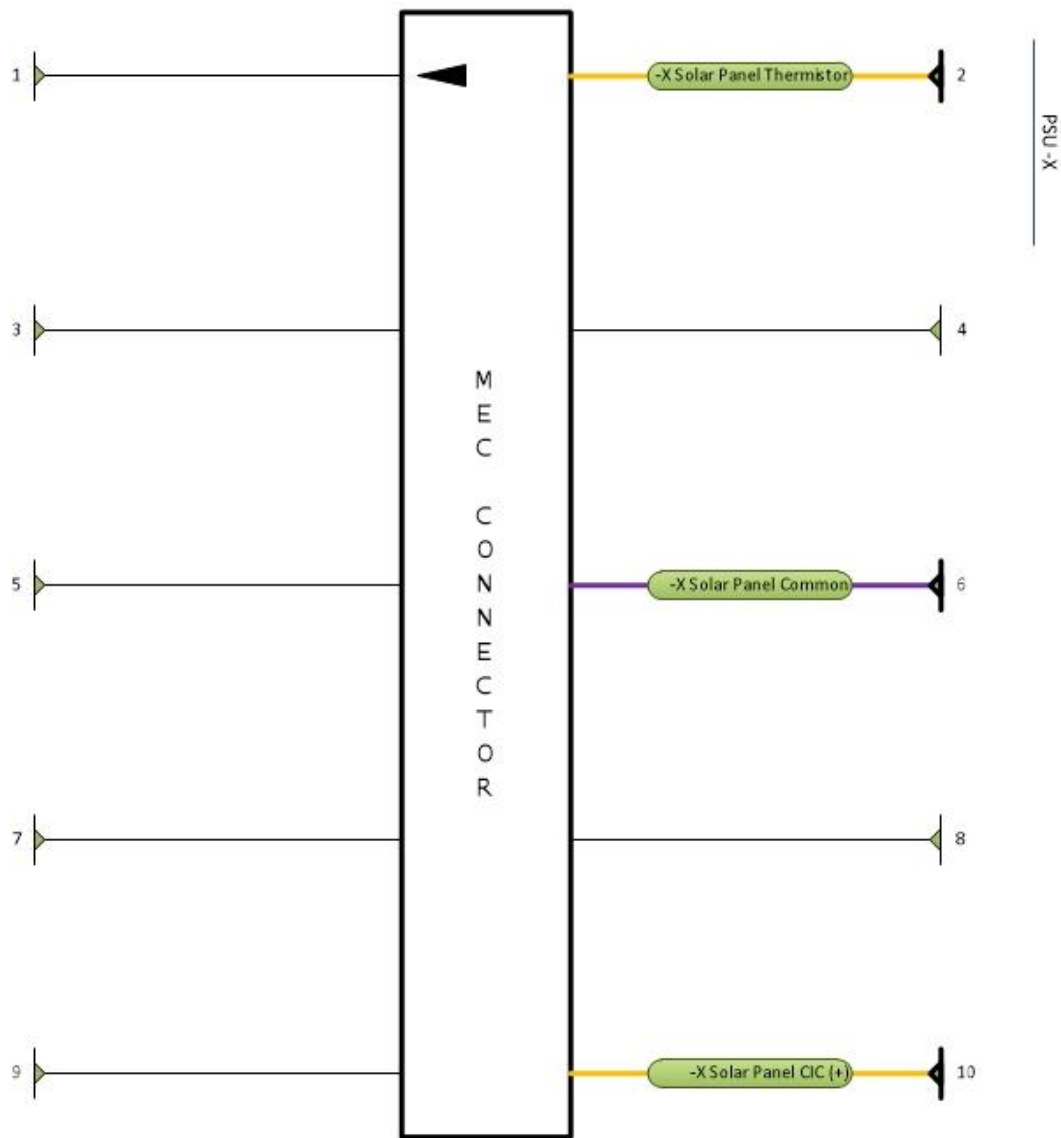
Figure 8: PSU System +X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

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Table 6: -X PCB edge mates to MEC1-105-02-L-D-NP-A connector on -X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	-X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	-X Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A



Legend	
System	
ANTENNAS	Blue
EXPERIMENTS	Green
ALL	Purple
PSU/BATT	Yellow
UMBILICAL	Red
RF	Black
In use	Triangle
Not in use	Square

Figure 9: PSU System -X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

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Table 7: +Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on +Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	+Y Antenna Sensor	Switch	N/A	PSU	N.O.	48
5	N/C					
6	+Y Solar Panel Common					Ground Plane
7	N/C					
8	+Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	50
9	N/C					
10	+Y Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

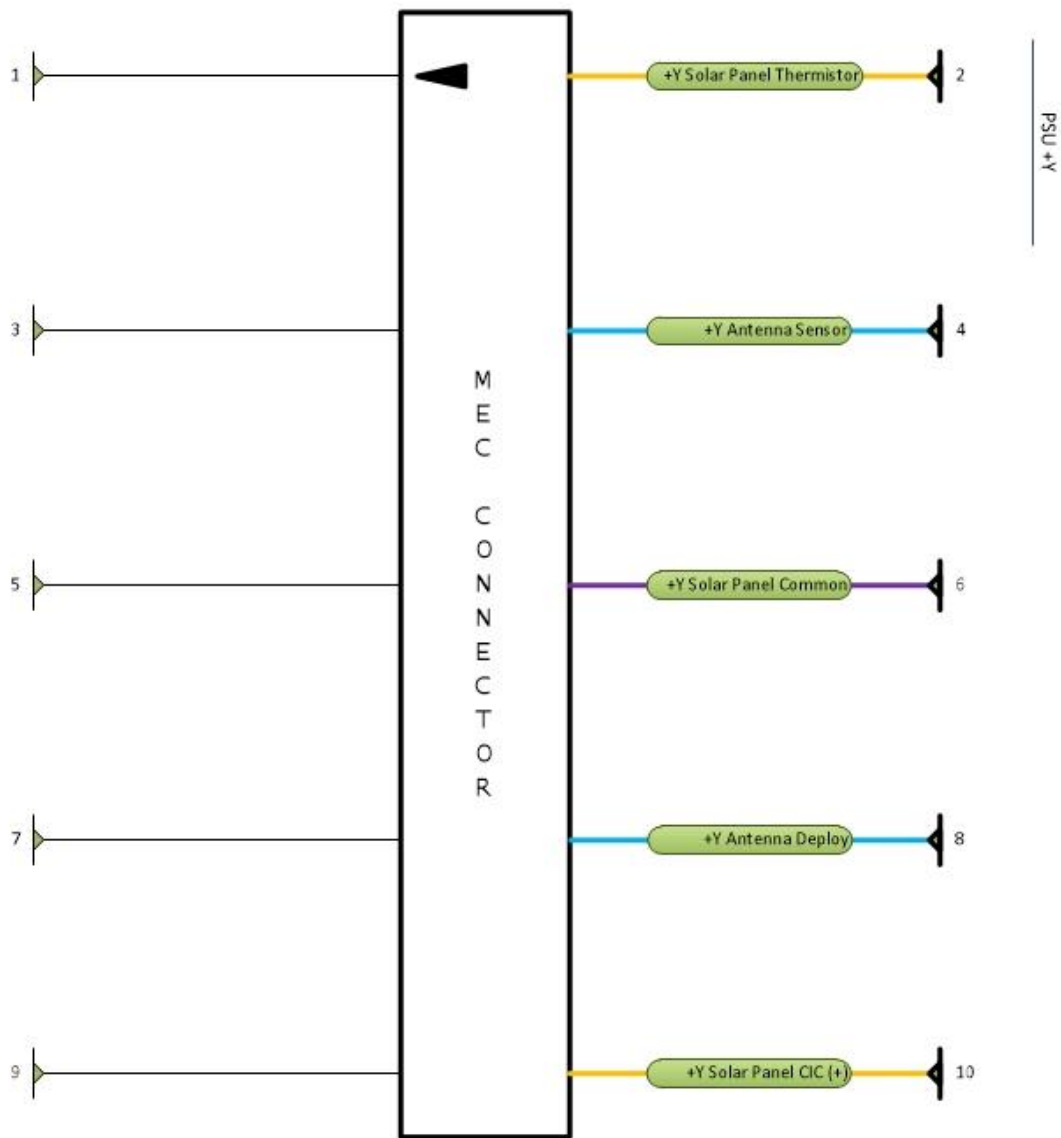


Figure 10: PSU System +Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

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Table 8: -Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on -Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	-Y Antenna Sensor	Switch	N/A	PSU	N.O.	46
5	N/C					
6	-Y Solar Panel Common					Ground Plane
7	N/C					
8	-Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	44
9	N/C					
10	-Y Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

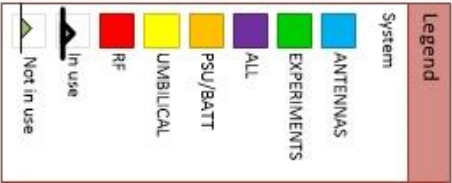
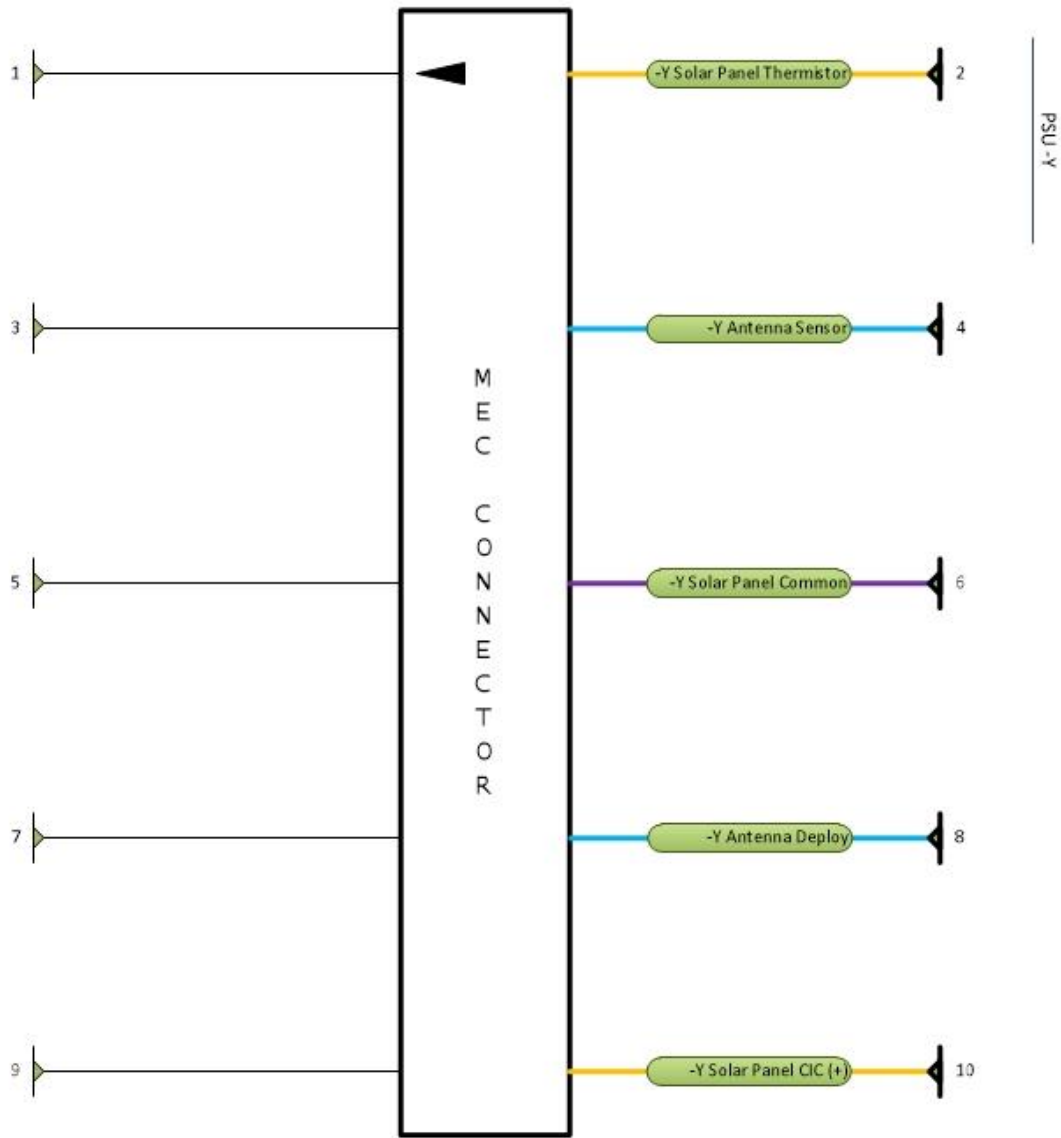


Figure 11: PSU System -Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

7 Battery System

7.1 System Requirements Applicable to Battery PCB 1 System (BATT1)

2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.																		
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.																		
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.																		
3.3.1	The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.																		
3.4.1	The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).																		
3.4.2	The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.																		
3.5.3	The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.																		
3.5.4	The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.																		
3.10.1	The satellite shall collect telemetry data.																		
3.10.2	The telemetry data shall include at a minimum, measured parameters as shown in Table 3. <table border="1"> <thead> <tr> <th>Parameter Name</th><th>Description</th></tr> </thead> <tbody> <tr> <td>CELL V</td><td>Voltages of battery cells</td></tr> <tr> <td>PANEL V</td><td>Voltages of solar panels</td></tr> <tr> <td>TOTAL I</td><td>Total DC current out of power system</td></tr> <tr> <td>PA I</td><td>DC current into RF power amp</td></tr> <tr> <td>BATTERY T</td><td>Temperature of battery</td></tr> <tr> <td>PANEL T</td><td>Temperatures of solar panels</td></tr> <tr> <td>TX T</td><td>Temperature of RF transmitter card</td></tr> <tr> <td>RX T</td><td>Temperature of RF receiver card</td></tr> </tbody> </table>	Parameter Name	Description	CELL V	Voltages of battery cells	PANEL V	Voltages of solar panels	TOTAL I	Total DC current out of power system	PA I	DC current into RF power amp	BATTERY T	Temperature of battery	PANEL T	Temperatures of solar panels	TX T	Temperature of RF transmitter card	RX T	Temperature of RF receiver card
Parameter Name	Description																		
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TOTAL I	Total DC current out of power system																		
PA I	DC current into RF power amp																		
BATTERY T	Temperature of battery																		
PANEL T	Temperatures of solar panels																		
TX T	Temperature of RF transmitter card																		
RX T	Temperature of RF receiver card																		
3.10.3	The measured parameters shall be sampled at least every 15 seconds.																		



7.2 Volume Requirements Applicable to Battery PCB 1 System

7.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 4.0 mm from the -Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 1.0 mm from the -Z surface of the PC board in the rest of the board area.

7.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 17.0 mm from the +Z surface of the PC board.

7.3 Interface Control Documents Applicable to Battery PCB 1 System

[AMSAT Fox-1 IHU to Battery Interface Control Document](#)

7.4 Battery PCB 1 System Bus Connections

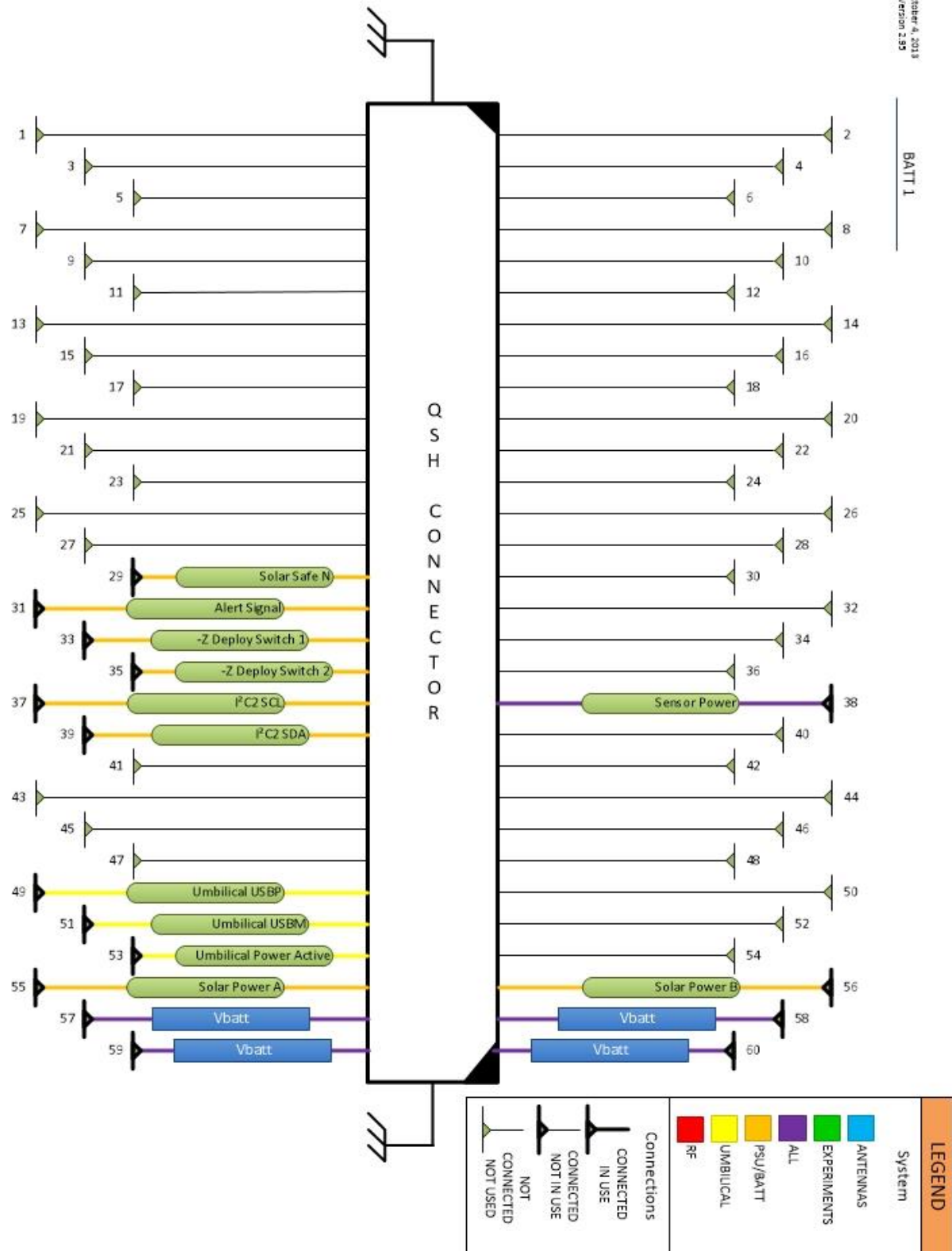


Figure 12: Battery 1 System Bus Connection Pin Assignments

7.5 Battery PCB 1 System External Connections

7.5.1 Umbilical as USB mini type B receptacle

7.5.2 Remove Before Flight as 3.5mm normally open TS jack

Table 9: Battery 1 External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
USB 1	USB +5 VDC	Analog	5 VDC	USB CONNECTOR	N/A	N/A
USB 2	USB Data - (USBM)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	51
USB 3	USB Data + (USBP)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	49
USB 4	Ground			USB CONNECTOR	N/A	Ground Plane
RBF 1	Solar Safe N	Analog	N/A	3.5mm N.O. TS jack	N/A	40

*When external supply is connected to USB port

7.6 Battery PCB 2 System Bus Connections

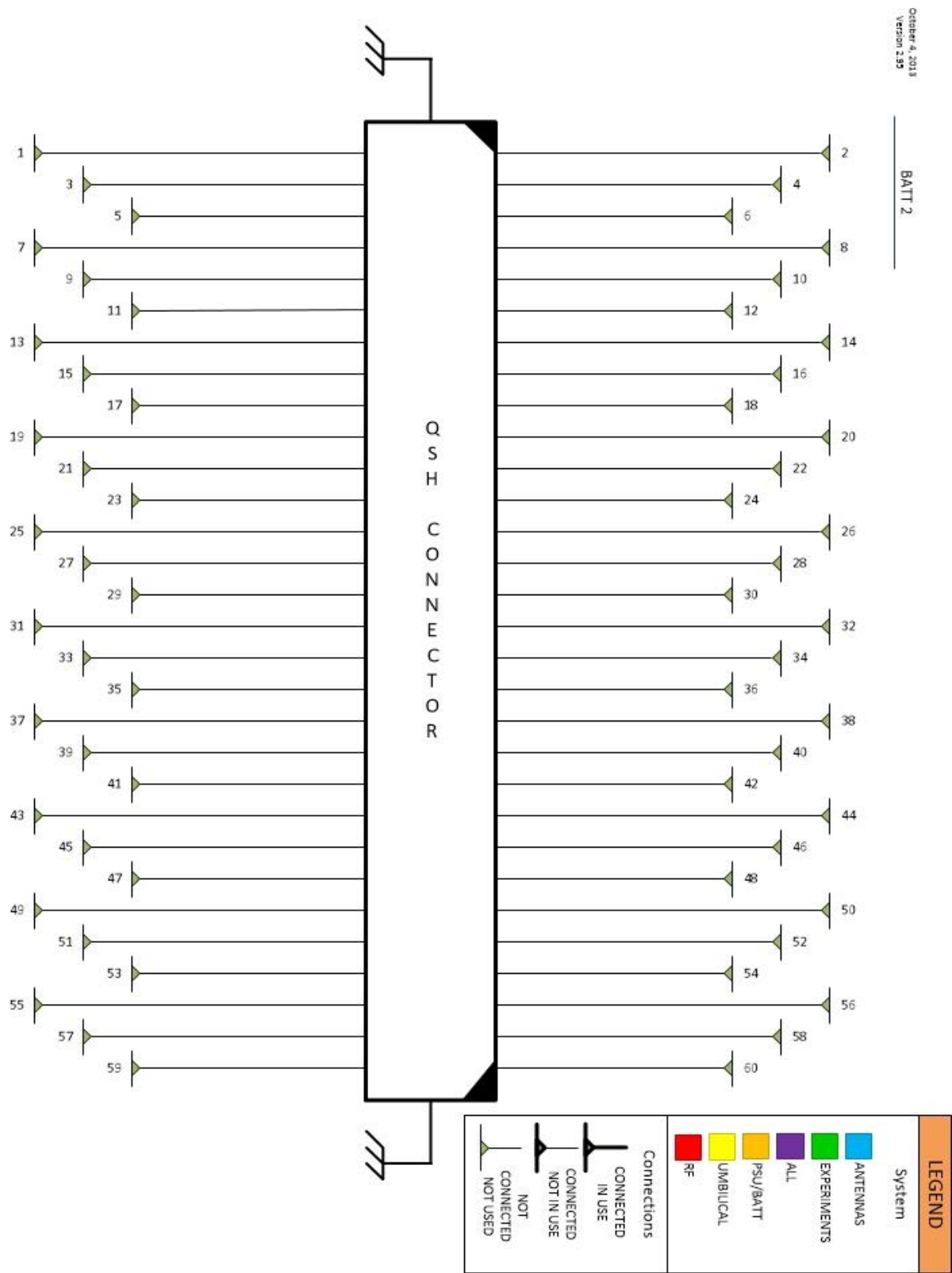


Figure 13: Battery 2 Bus Connection Pin Assignments



8 Experiment Payload Systems 1 through 4

8.1 System Requirements Applicable to Experiment Payload Systems 1-4

2.1.4	The satellite shall provide mass for an experiment payload up to 100 g.
2.1.5	The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.
2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
3.6.1	The satellite shall provide DC power for experiment payloads.
3.6.2	The satellite shall provide a means to activate and deactivate the experiment payloads.
3.6.3	The satellite shall provide a means to telemeter data from the experiment payloads.

8.2 Initial Surge Current Limits

8.2.1 All Experiment designs shall limit initial inrush current to 0.1 Amperes.

8.3 Volume Requirements Applicable to Experiment Payload System 1

8.3.1 No components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall protrude from the -Z surface of the PC board.

8.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.4 Interface Control Documents Applicable to Experiment 1 Payload System

[AMSAT Fox-1 IHU to Experiment 1 Interface Control Document](#)

8.5 Volume Requirements Applicable to Experiment Payload Systems 2 and 3

8.5.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

8.5.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.6 Volume Requirements Applicable to Experiment System 4

8.6.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.



8.6.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5.0 mm from the +Z surface of the PC board.

8.7 Interface Control Documents Applicable to Experiment 4 Payload System
[AMSAT Fox-1 IHU to Experiment 4 Interface Control Document](#)

8.8 Experiment Payload 1 Systems PCB Bus Connections

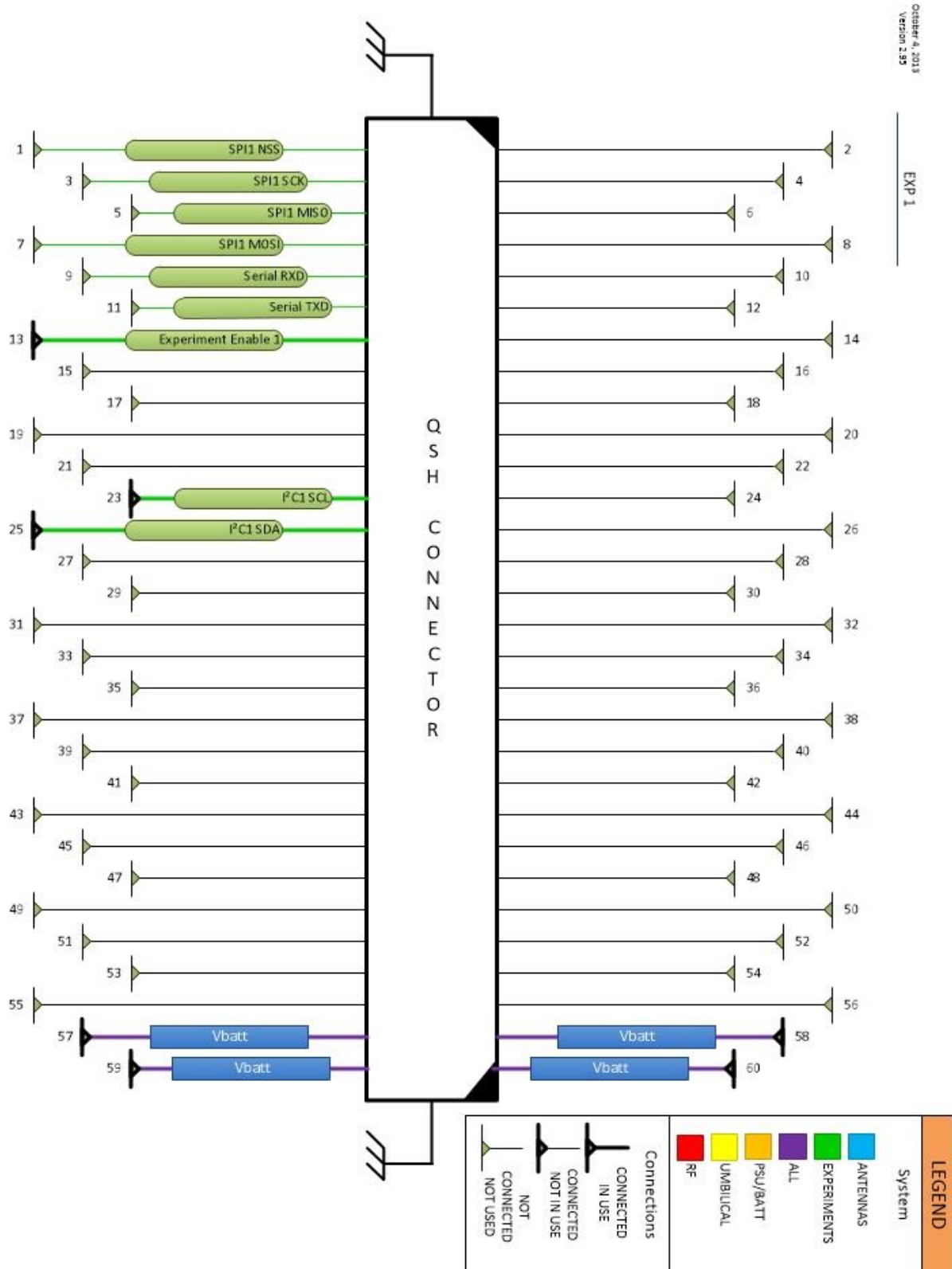


Figure 14: Experiment Payload 1-3 Systems Bus Connection Pin Assignments

8.9 Experiment Payload 4 System PCB Bus Connections

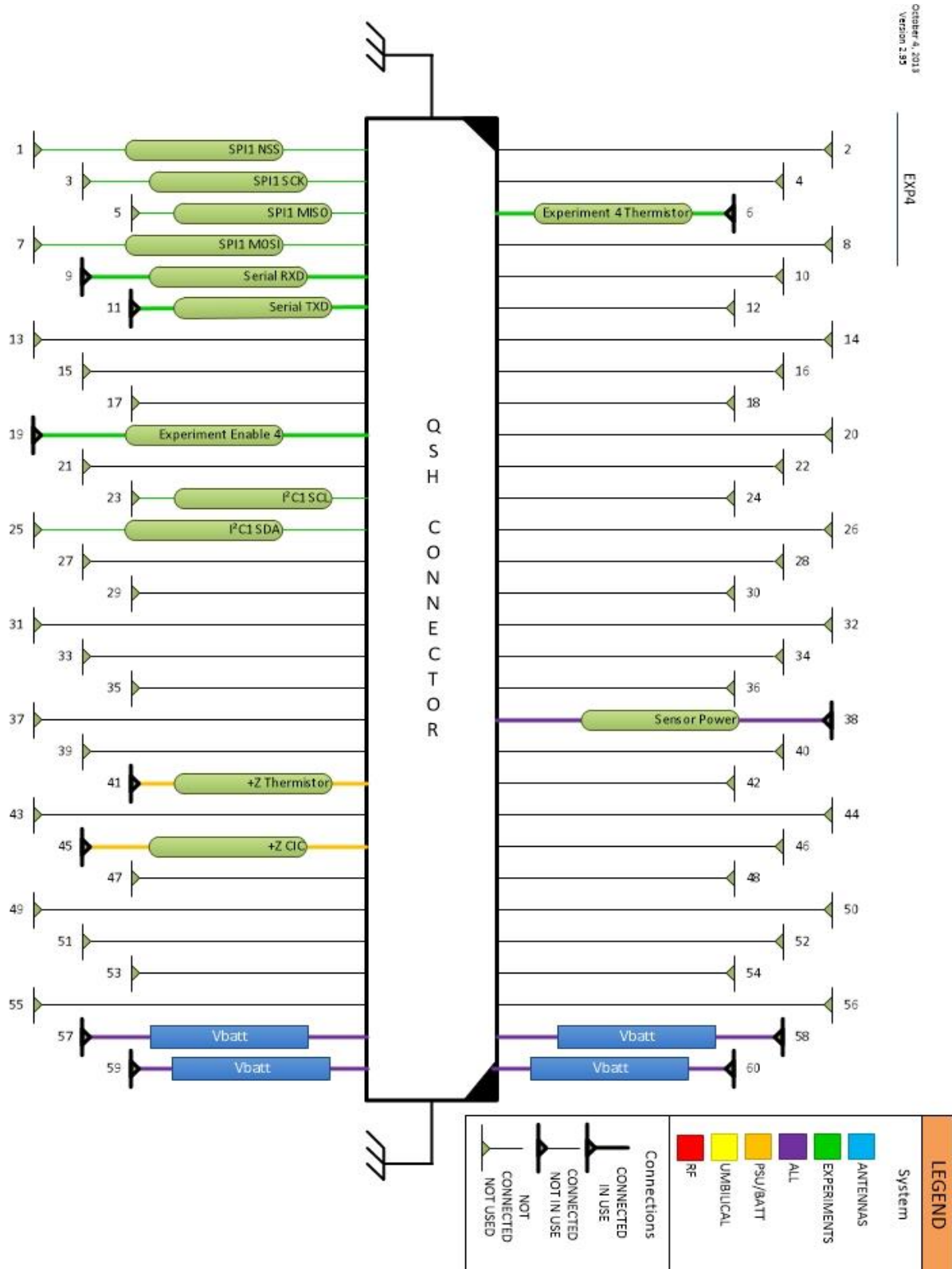


Figure 15: Experiment Payload 4 System Bus Connection Pin Assignments

8.10 Experiment Payload 4 System PCB External Connections

8.10.1 Three connections using Samtec FSI-105-06-L-S-AD connector

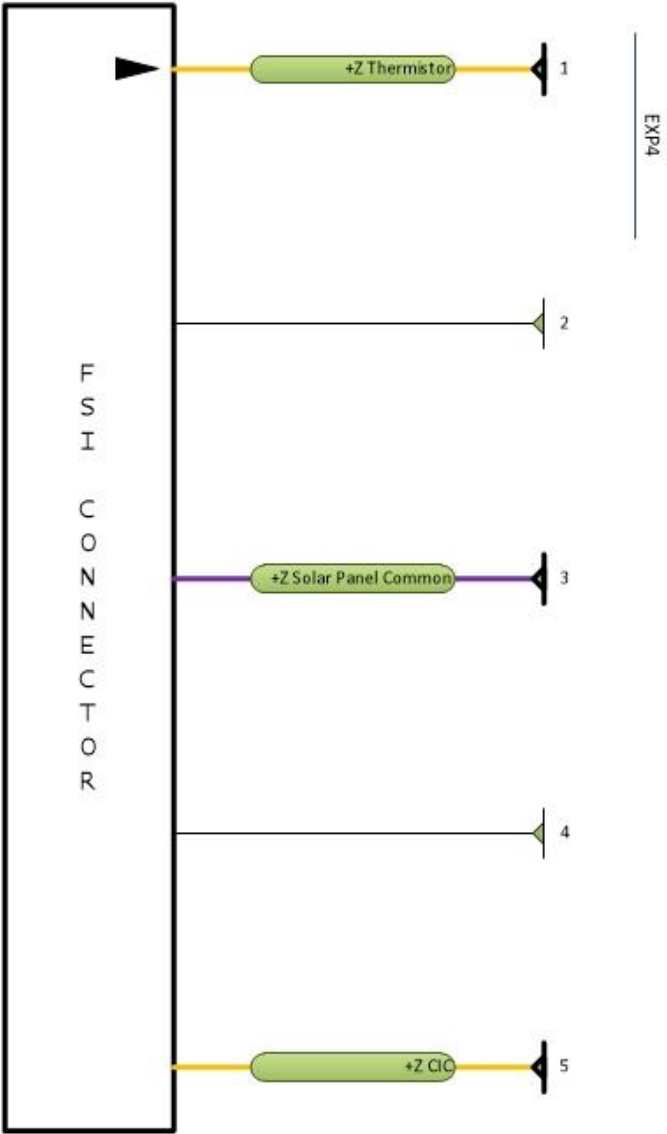
8.10.1.1 1 contact +Z Solar Panel Thermistor

8.10.1.2 1 contact +Z Solar Panel CIC +

8.10.1.3 1 contact common or - for above two connections

Table 10: +Z PCB face FSI-105-06-L-S-AD connector mates to pads on +Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	+Z Thermistor	Analog	N/A	N/A	N/A	PSU	41
2	N/C						
3	+Z Solar Panel Common						Ground Plane
4	N/C						
5	+Z CIC	Power	N/A	N/A	N/A	PSU	45

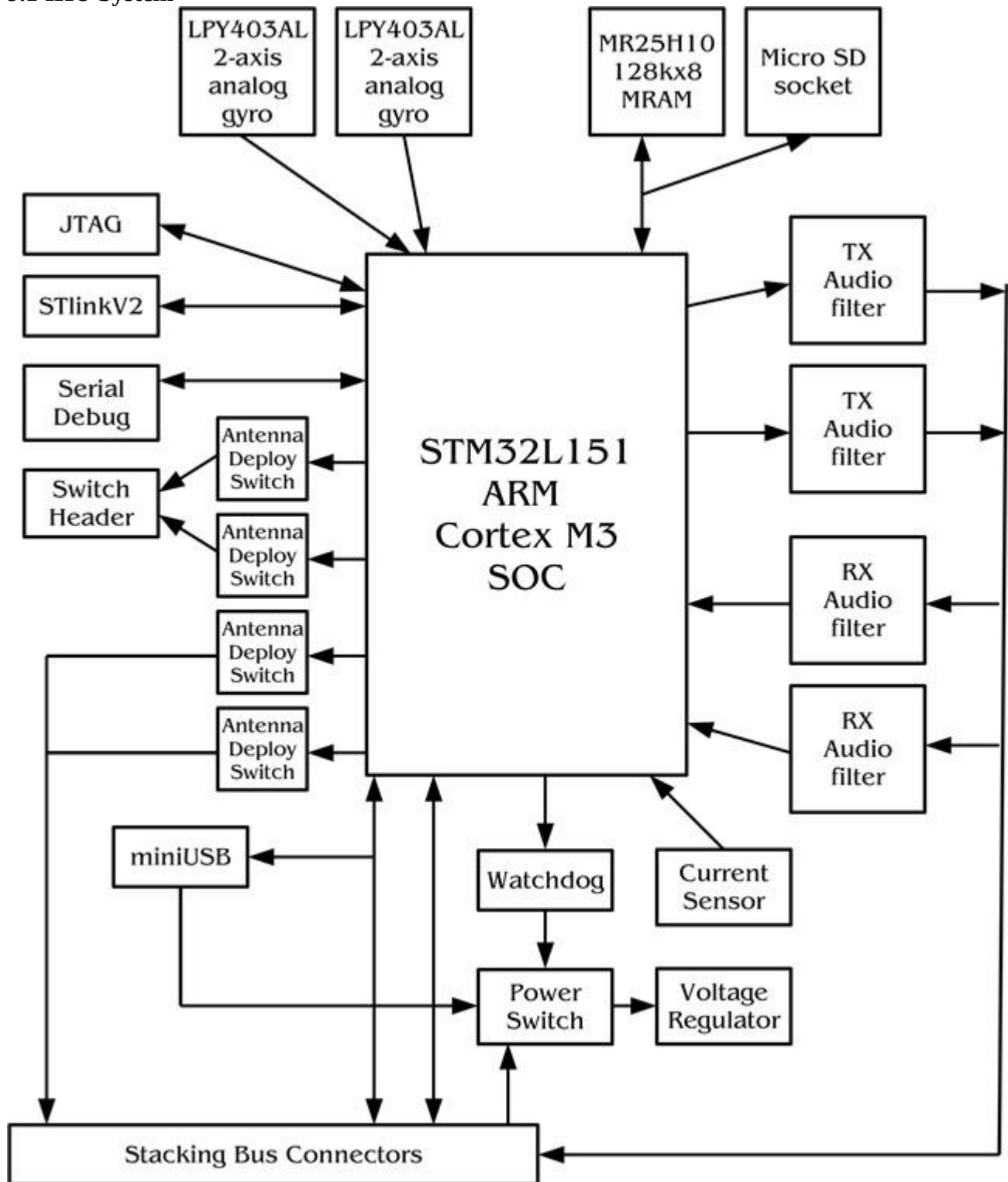


Legend	
System	
ANTENNAS	Blue
EXPERIMENTS	Green
ALL	Purple
PSU/BATT	Orange
UMBILICAL	Yellow
RF	Red
In use	Black triangle pointing right
Not in use	White triangle pointing right

Figure 16: Experiment Payload 4 System FSI-105-06-L-S-AD
Connection Pin Assignments

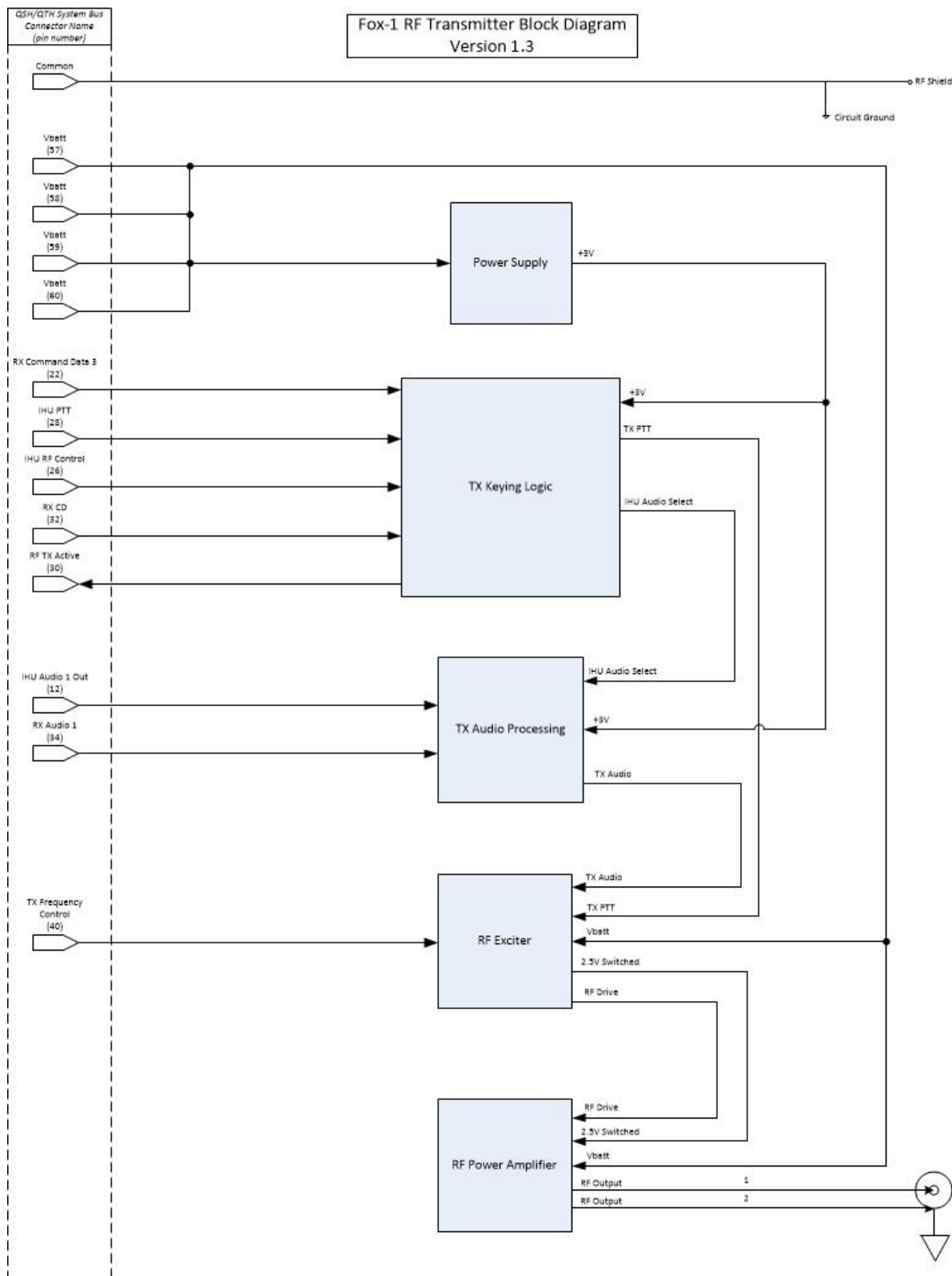
9 System Block Diagrams Reference

9.1 IHU System



9.2 RF System

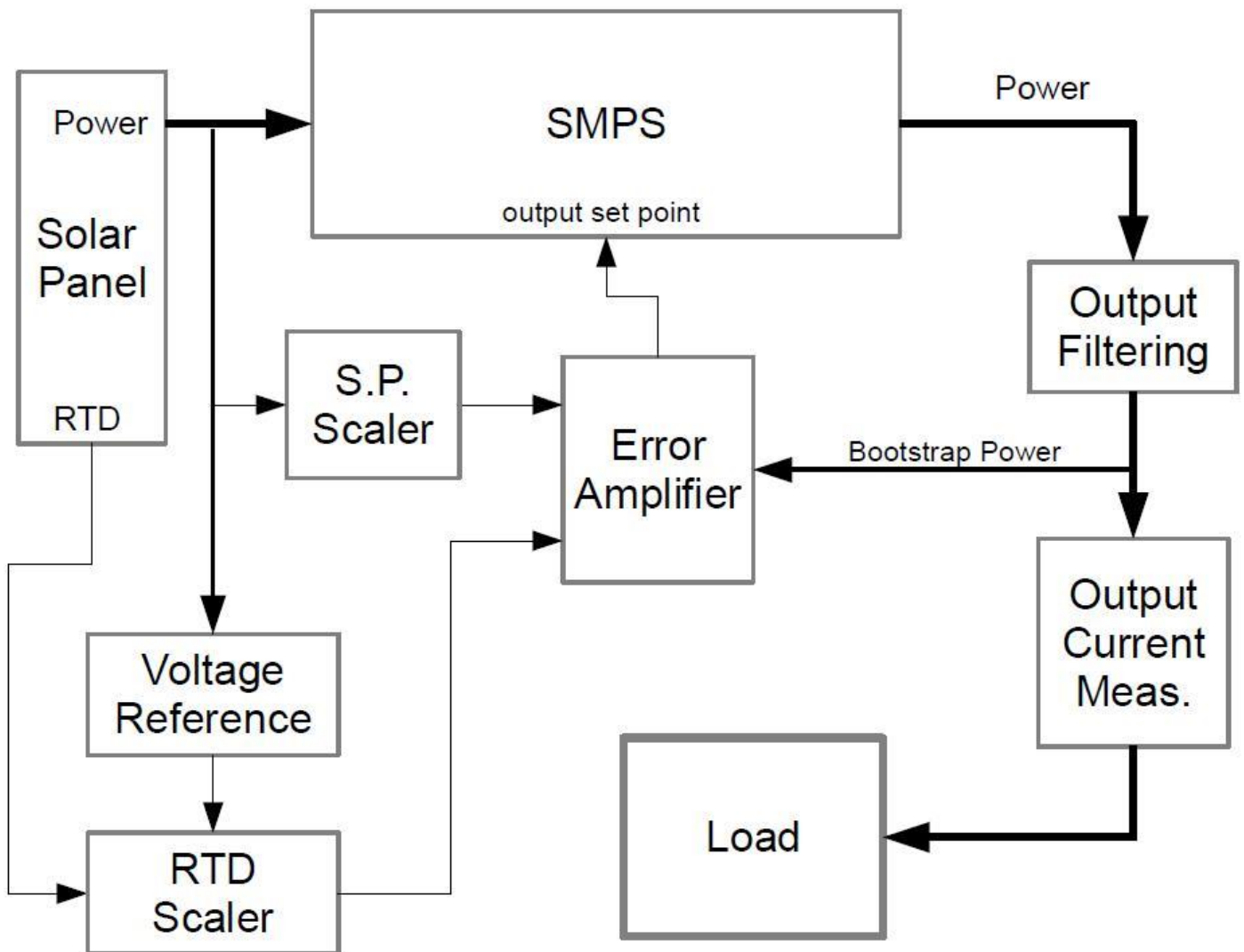
9.2.1 RF Transmitter Block Diagram





9.2.2 RF Receiver Block Diagram (TBR)

9.3 PSU System





10 System Interconnection References

10.1 Bus Connectors

10.1.1 Samtec QTH-030-02-L-D-A and QSH-030-01-L-D-A connectors

10.1.2 QTH connector shall be mounted on the +Z surface of each circuit board except the Receive Antenna PCB / GPS Payload circuit board

10.1.3 QSH connector shall be mounted on the -Z surface of each circuit board

10.2 Bus Connector Documentation

10.2.1 [Samtec QSH](#)

10.2.2 [Samtec QTH](#)

10.2.3 [Samtec QxH High Speed Characterization Report](#)

10.2.4 [Samtec QxH Single Ended Channel Properties](#)

10.3 External Connectors

10.3.1 Samtec MEC1-105-02-L-D-NP-A connector mounted on +X, -X, +Y, -Y Solar Panels

10.3.2 Samtec FSI-105-06-L-S-AD connector mounted on -Z face of RF Transmitter System PCB and +Z face of Experiment Payload 4 System PCB

10.4 External Connector Documentation

10.4.1 [Samtec MEC1](#)

10.4.2 [Samtec MEC1 Qualification Testing](#)

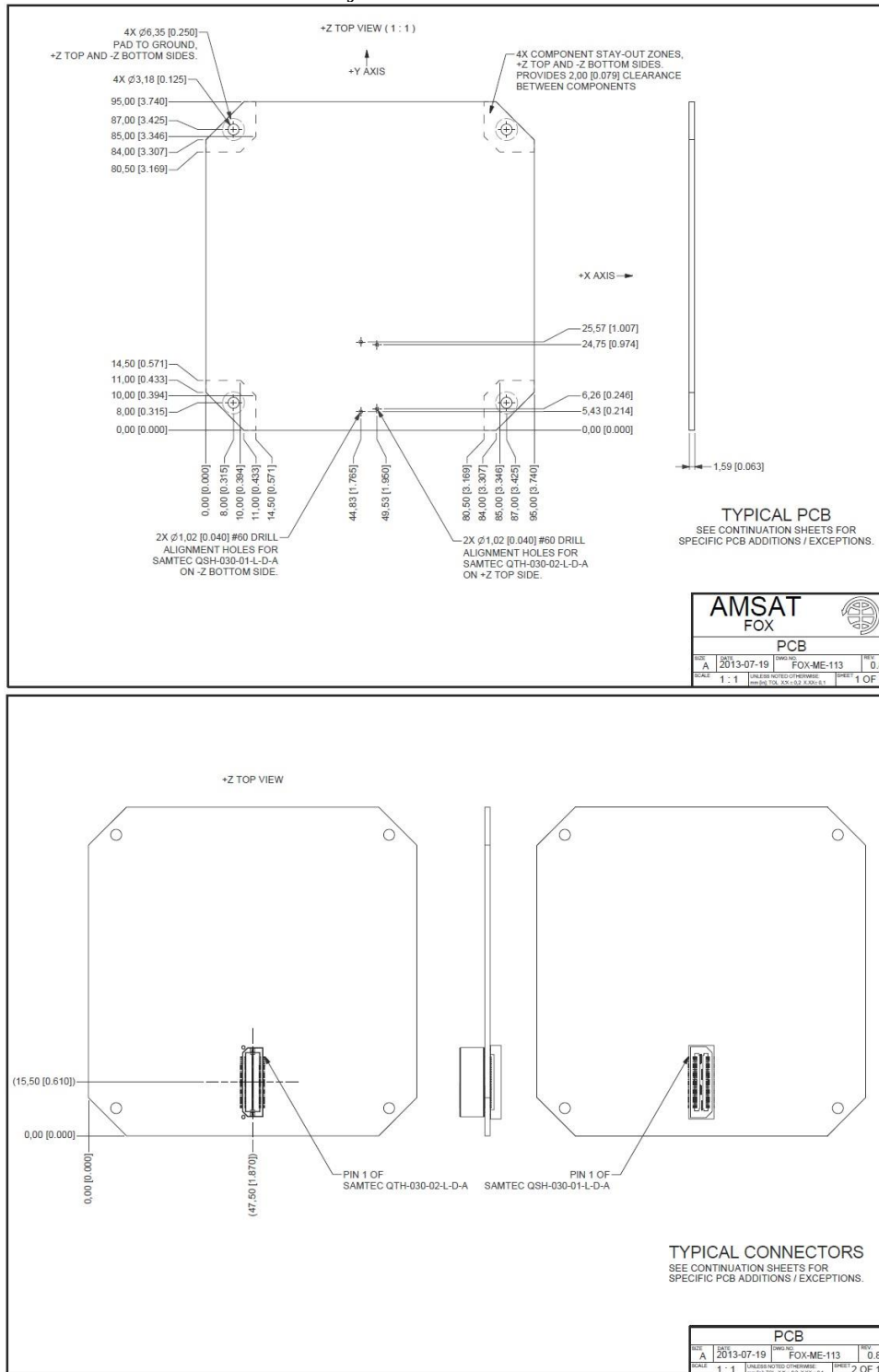
10.4.3 [Samtec FSI](#)

10.5 PCB Connector Layout Documentation

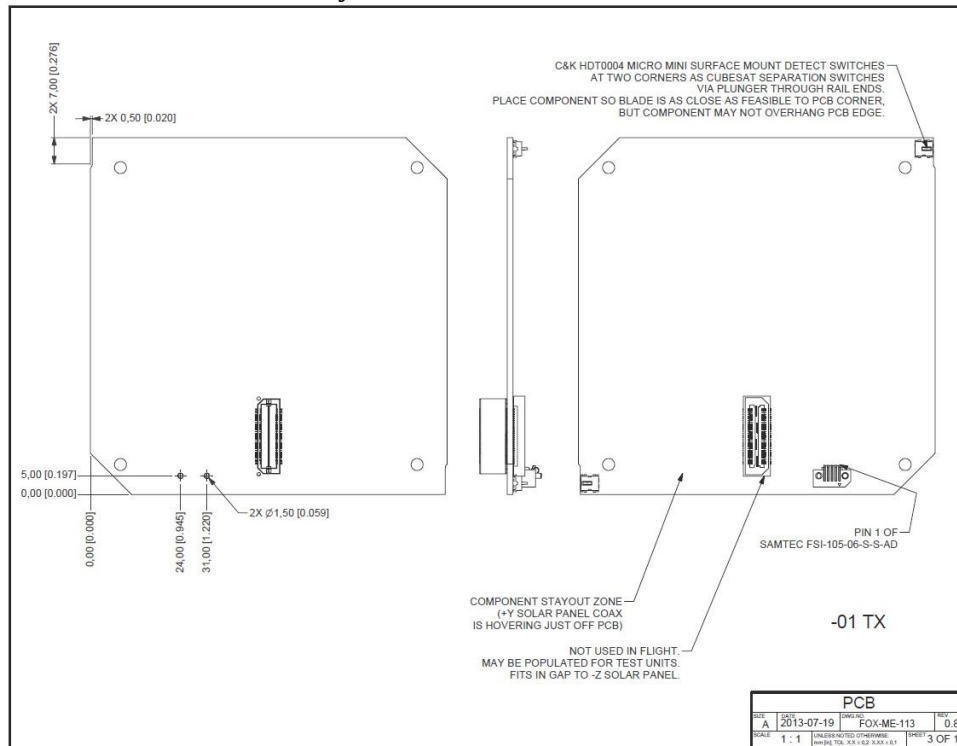
10.5.1 [FOX-ME-113_PCB.pdf](#)

10.6 Systems PCB Connector Layout

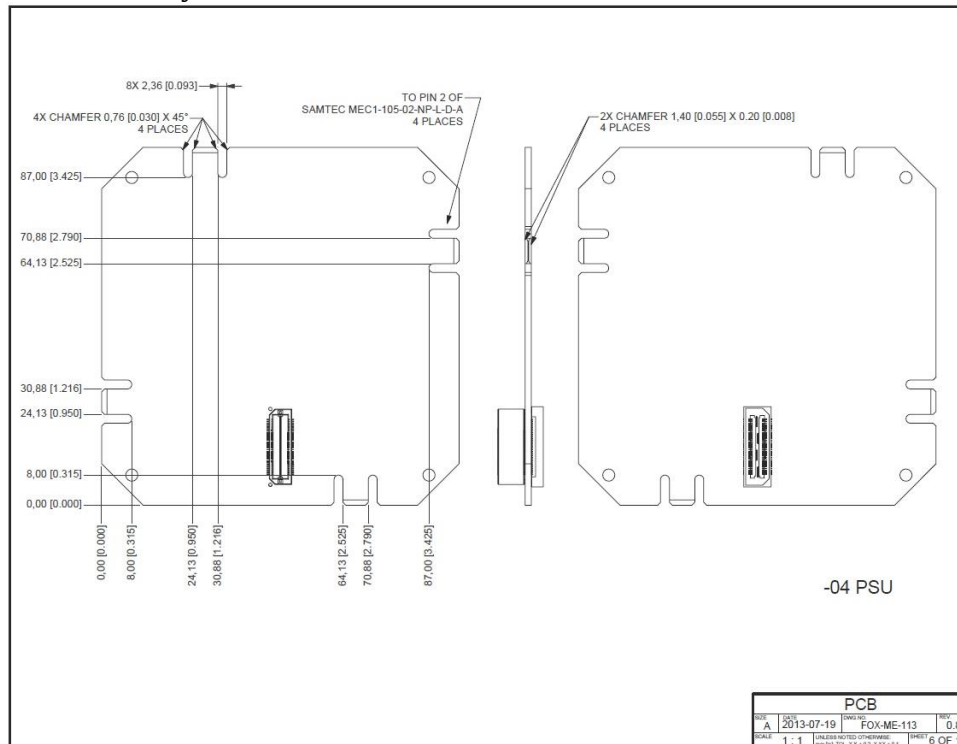
10.6.1 Common to All Systems



10.6.2 RF Transmitter System

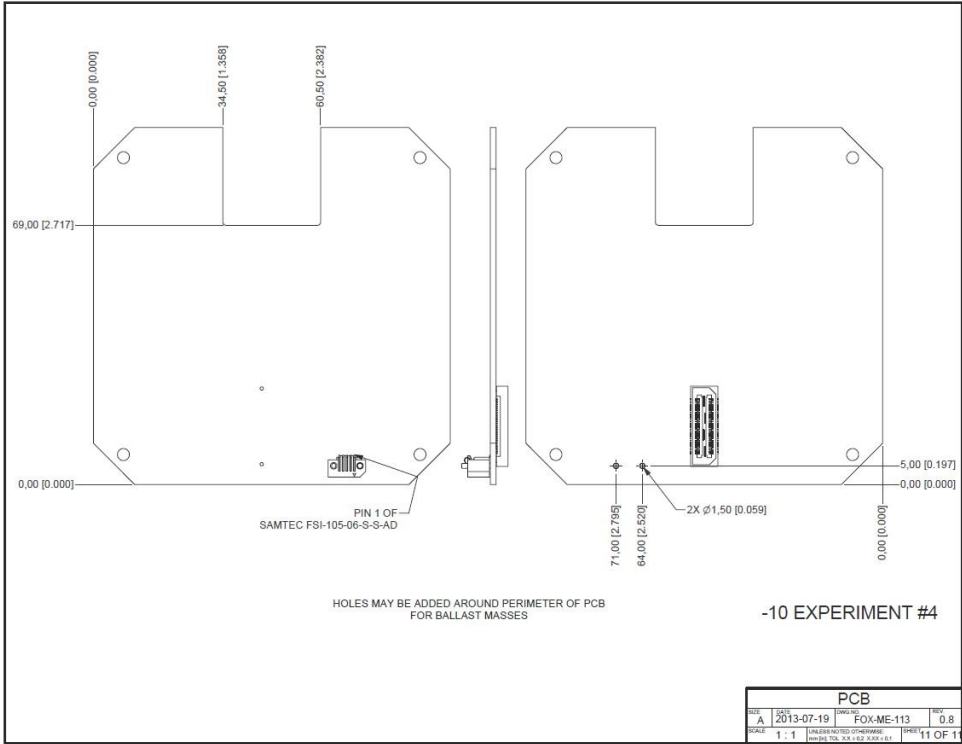


10.6.3 PSU System





10.6.4 Experiment 4 System



Date: June 29, 2012

Version: 2.0

AMSAT Fox-1

Attitude Determination Experiment Payload System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project attitude determination experiment payload.

The *Fox-1* satellite is a 1 Unit CubeSat with a primary mission of providing amateur radio communications. In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie, through an AMSAT sponsored senior design project.

The goal of the experiment will be to measure the spin rate and direction, about the Z axis of the satellite, and any off Z-axis “wobble”.

1.1 Document History

DATE	VERSION	SUMMARY
November 9, 2011	1.0	From Draft F
December 4, 2011	1.01	Fix formatting
December 23, 2011	1.03	Update references to other documents
December 27, 2011	1.04	Update 2.1.13 for QTH/QSH connectors
February 12, 2011	1.10	Change bus to SPI and add power signal Removed references to multiple PCBs and conflicting component placement Adjust PCB stay out zone and other requirements per latest mechanical revisions
June 29, 2012	2.0	Modified extensively due to move of experiment equipment to the IHU card

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the experiment payload at the system (i.e. "black box") level. It is intended to be used to by the hardware,

AMSAT *Fox-1*
Attitude Determination Experiment Payload System Requirements



software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity are *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-1*, Concept of Operations, Version 1.03, September 19, 2011
2. AMSAT *Fox-1*, System Requirements Specification, Version 1.1, April 29, 2012
3. AMSAT *Fox-1* IHU to Attitude Determination Experiment Interface Control Document, Version 2.0, June 29, 2012

2 General Requirements

2.1 Physical Requirements

- 2.1.1 The experiment payload shall be constructed on the satellite IHU system PCB.

2.2 Environmental Requirements

- 2.2.1 The experiment payload shall be designed for -40C to +70C operating temperature.

3 Functional Requirements

3.1 Experiment Data

- 3.1.1 The experiment payload shall measure the spin rate and direction about the Z axis of the satellite.
- 3.1.2 The experiment payload shall measure any deviation (*wobble*) of the Z axis of the satellite caused by the spin of the satellite.
- 3.1.3 The experiment payload data shall have an accuracy of 1 degree.
- 3.1.4 The experiment payload shall be able to resolve the rate of spin in the range of 0 to 50 degrees per second. The experiment payload shall be able to resolve the deviation of the Z axis (*wobble*) in the range of 0 to 50 degrees.

3.2 Satellite Interface

- 3.2.1 The experiment data shall be directly collected by the satellite IHU system.

3.3 Power

- 3.3.1 The experiment payload shall receive electrical power from the satellite battery and photovoltaic panels.
- 3.3.2 The electrical power voltage will be nominally DC 3.6 V.
- 3.3.3 The satellite IHU system will activate and deactivate the experiment payload as necessary.
- 3.3.4 The electrical power drawn by the experiment payload shall not exceed 200 mW.

3.4 Experiment Data

- 3.4.1 The IHU system shall process the experiment data for telemetry transmission†.
- 3.4.2 The IHU system shall sample the experiment data at a rate sufficient to provide telemetry data at least every 15 seconds.
- 3.4.3 The experiment payload data shall include the following measured and calculated parameters:

Parameter Name	Description
SPIN RATE	Rate of spin of the satellite about the Z axis, in degrees per minute
SPIN DIRECTION	Direction of spin of the satellite about the Z axis (+X or -X)
DEVIATION	Deviation (<i>wobble</i>) of +Z axis caused by satellite spin
UP TIME	Total seconds since experiment payload power-up or reset

†Note that the telemetry data frame is specified in the AMSAT Fox-1 IHU to Attitude Determination Experiment Interface Control Document.

4 External Interface Documents

To fully specify the experiment payload technical requirements, the following documents must also be provided;

1. AMSAT Fox-1 IHU to Attitude Determination Experiment Interface Control Document

5 Summary

The Fox-1 satellite attitude determination experiment payload will provide data on the spin and wobble of the passive-magnetically stabilized satellite. This includes the first known measurements of the wobble about the Z axis of a magnetically stabilized AMSAT satellite.

Date: June 29, 2012

Version: Version 2.0

AMSAT Fox-1

IHU to Attitude Determination Experiment Interface Control Document

1 Introduction

This document specifies the message interface and the power activation interface between the Internal Housekeeping Unit (IHU) system and the Experiment Payload, as required per the AMSAT Fox-1 Attitude Determination Experiment Payload System Requirements Specification document.

The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

1.1 Document History

DATE	VERSION	SUMMARY
February 12, 2012	1.0	From Draft and now SPI
February 15, 2012	1.01	Add SPI Bus Hardware Interface Requirements Change to DATA block types and values
February 20, 2012	1.02	Add SPI framing and CRC polynomial
February 20, 2012	1.03	Requirements Tracking Changes
February 21, 2012	1.04	Deviation corrected from 90 to 50 per Experiment System Requirement 3.1.5
February 26, 2012	1.05	Corrected description of SPIN RATE field in Table 6 to read seconds instead of minutes
March 7, 2012	1.06	Change 6.1.1.1 high state signal to $\geq 2.4V$
April 5, 2012	1.07	Add new DATA field MEMS GYRO STATUS
April 9, 2012	1.08	Added requirement 2.2.4
April 11, 2012	1.1	Add bits to MEMS GYRO STATUS
April 24, 2012	1.11	Set logic level Low as $\leq 0.2V$ in 6.1.1.2
June 29, 2012	2.0	Modified extensively due to move of experiment equipment to the IHU card

1.2 Document Scope

The purpose of this document is to specify the data format for the communications between the Attitude Determination Experiment and the IHU system, as described in the

AMSAT *Fox-1*
IHU to Attitude Determination Experiment ICD



AMSAT *Fox-1* Attitude Determination Experiment Payload System Requirements Specification.

1.3 References

1. AMSAT *Fox-1* System Requirements Specification, Version 1.1, April 29, 2012
2. AMSAT *Fox-1* Experiment Payload System Requirements Specification, Version 2.0, June 29, 2012
3. AMSAT *Fox-1* IHU Software Architecture Specification, Draft E, January 19, 2012

2 Telemetry Content Requirements

2.1 Telemetry Data Block

2.1.1 The telemetry data block shall contain the data fields as shown in Table 1.

Table 1

Field	Size (Bytes)	Type	Value	Description
SPIN RATE	2	Signed integer	Variable -50 to +50	Rate of spin of the satellite about the Z axis, in degrees per second. Negative indicates -X spin direction, positive indicates +X spin direction.
DEVIATION	2	Unsigned integer	Variable 0 to +50	Deviation (wobble) of Z axis in degrees.
UP TIME	2	Unsigned integer	Variable 0 to 65535	Total seconds since experiment payload power-up or reset

Date: August 27, 2013

Version: Version 2.00

AMSAT Fox-1

IHU to RF System Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the RF System, as required per the AMSAT Fox-1 System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
March 24, 2012	1.0	Initial version
March 24, 2012	1.1	Add 2 nd RX Audio Out section 3.4.1
March 26, 2012	1.2	Section 3.2 rename Zombie to IHU Control, rename Audio to Audio 1, Section 3.4 remove RX Audio 2, section 4 removed entirely
March 26, 2012	1.3	Many updates using input from teams
March 30, 2012	1.4	Update 3.4.1.1 to clarify that receive signal CTCSS is responsible for state
March 31, 2012	1.5	3.3.1.3 updated to read no less than 100 mS
April 24, 2012	1.6	Update impedances and voltages to match SDS
June 18, 2012	1.7	Update 3.3.1.5 per PDR change to SRS, remove RESET add IHU OFF and IHU ON commands, signal characteristic updates per PDR, 3.4.1.2 to indicate command station signal strength
September 13, 2012	1.8	Remove IHU CONTROL signal, match signal characteristics to system design specification
September 16, 2012	1.9	Changes to 3.3.1.1 and Table 4 per Tony
September 18, 2012	1.91	Removed Command Table (section 3.3) and re-stated section 3.3 requirements accordingly
February 17, 2013	1.92	Incorporate system bus signal nomenclature and pin assignment changes
August 27, 2013	2.00	Move RX Command Decoder to IHU, give IHU more responsibility for RF System control, rename RSSI to RX CD, add RSSI to Pin 10

1.2 Document Scope

The purpose of this document is to specify the signal types, levels, and direction for connections between the IHU and the RF System as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1* System Requirements Specification
2. AMSAT *Fox-1* System Design Specification
3. AMSAT *Fox-1* IHU Software Architecture Specification

2 General Requirements

2.1 Telemetry

- 2.1.1 RF System Telemetry values shall be conveyed as analog voltage levels sent from the RF System to the IHU System.
- 2.1.2 The IHU System shall convert the analog signals to digital representations.
- 2.1.3 Audio signals for the purpose of conveying telemetry via sub-audible audio frequencies shall be sent from the IHU System to the RF System.

2.2 RF System Control

- 2.2.1 Control of the RF System shall be accomplished by means of digital signals sent from the IHU System to the RF System.

2.3 Satellite System Command

- 2.3.1 Command data for the purpose of controlling the satellite shall be processed by the IHU System and sent to the RF System.
- 2.3.2 Command data shall be conveyed to the RF System via digital signals.

2.4 Operational Components

- 2.4.1 Demodulated baseband audio signals shall be passed from the RF System to the IHU System for processing.
- 2.4.2 Baseband audio signals shall be passed from the IHU System to the RF System for transmission.
- 2.4.3 Operational Status signals shall be conveyed as digital signals sent from the RF System to the IHU System.

2.5 Signal Transmission

- 2.5.1 Signals shall use the pin assignments shown in the Fox-1 System Design Specification document.
- 2.5.2 Signal connections shall comply with the impedance and signal type shown in the parameters for each type of signaling.

2.6 Signal Type Definitions and Levels

- 2.6.1 **Analog:** 0 – 3.0 VDC analog voltage.
- 2.6.2 **Digital:** 3.0 VDC CMOS logic levels.

3 Signal Connection Requirements

3.1 Telemetry

3.1.1 The RF System shall provide raw telemetry values from the RF System components as shown in Table 1.

Table 1

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 k Ω	IHU	
4	TX Temperature	Analog	0 - 3.0 V	TX	30 - 60 k Ω	IHU	Thermistor Circuit
8	RX Temperature	Analog	0 - 3.0 V	RX	30 - 60 k Ω	IHU	Thermistor Circuit

3.1.1.1 The values shall be updated at a rate to provide new samples at least every 15 seconds.

3.2 RF System Control

3.2.1 The IHU System shall provide control and audio signals to the RF System as shown in Table 2.

Table 2

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
12	IHU Audio 1 Out	Analog	0 - 3 V (audio)	IHU	> 10 k Ω unbal.	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
26	IHU RF Control	Digital		IHU		TX	HIGH = IHU Controls RF LOW = Standalone Analog Transponder
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT

3.2.1.1 IHU RF Control when High shall indicate IHU presence and control of the RF PTT and audio.

3.2.1.2 IHU RF Control when Low shall indicate loss of IHU control causing the RF System to operate as a standalone carrier operated transponder passing audio directly from the receiver uplink to the transmitter downlink.

3.2.1.3 IHU PTT signal when High shall key the RF transmitter on.

3.3 Satellite System Command

3.3.1 The IHU System shall provide ground station command signals to the RF System as shown in Table 3.

Table 3

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
22	RX Command Data 3	Digital		IHU		TX	(Most Significant Bit) HIGH = Inhibit Transmit

3.3.2 An INHIBIT Command (RX Command Data 3 = HIGH) shall cause the RF System to cease RF transmissions without regard to the state of any other RF System Control signals.

Note that the control interface will be specified in a separate document.

3.4 Operational Components

3.4.1 The RF System shall provide operational and audio signals to the IHU System as shown in Table 4.

Table 4

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
10	RSSI	Analog	0 - 3.0 V	RX	30 - 60 k Ω	IHU	Received Signal Strength Indication
30	RF TX Active	Digital		TX		IHU	HIGH = RF TX on
32	RX CD	Digital	0	RX	0	TX IHU	HIGH = valid receive signal
34	RX Audio 1	Analog	0 - 3 V (audio)	RX	> 10 k Ω unbal.	IHU	10 Hz - 7 kHz bandwidth

3.4.1.1 RSSI signal shall indicate the relative strength of the received signal on the uplink.

3.4.1.2 RF TX Active signal when High shall indicate that the transponder uplink signal CTCSS hang timer is activating the RF transmitter.

3.4.1.3 RX CD signal shall indicate a valid received signal on the uplink.

Date: October 4, 2013

Version: Version 2.00

AMSAT *Fox-1*

IHU to PSU Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Power Supply (PSU) System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	Initial version
February 21, 2012	1.01	Clarify I ² C address
March 7, 2012	1.02	2.3.1 updated Vdd to 3.0V
August 7, 2012	1.03	Remove BATT1 data fields and adjust message accordingly
November 7, 2012	1.04	Added PSU CPU Temperature
December 27, 2012	1.10	Change from Bytes to Bits in Message Header Block, Message Data Block, Message Data (to allow for 12 bit ADC values)
January 2, 2013	1.11	Field sizes back to bytes account I ² C specifications
February 7, 2013	1.12	Correct typo in 3.3.1.1
August 22, 2013	1.13	Remove TOTAL I from Data block
August 22, 2013	1.14	Update I ² C speed to 10 kHz
October 4, 2013	2.00	Rework to eliminate STM32L and replace with ADS7828s

1.2 Document Scope

The purpose of this document is to specify the message format and the I²C bus hardware operation for the communications between the IHU and the PSU as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The PSU shall be the I²C Slave.

2.1.2.1 The IHU shall request the PSU to send the data for a specific Device and channel.

2.1.2.2 The PSU shall send that specific Device and channel data.

2.1.3 The IHU shall test for the presence both PSU system Devices.

2.1.4 The IHU shall only poll the PSU system Device(s) present, for data.

2.2 General Message Requirements

2.2.1 The IHU shall sample data at a rate sufficient to provide downlink telemetry data at least every 15 seconds.

2.2.2 For both Devices the ADS 7820 A/D converter shall always be commanded on (PD-0 bit = 1).

2.2.3 For both Devices the ADS 7820 Internal Reference shall always be commanded on (PD-1 bit = 1).

2.2.4 TFor both Devices the ADS 7820 shall always be commanded for single-ended inputs.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Standard (10 kHz).

2.3.3 The PSU system Device 1 I²C 7 bit address shall be 0x49.

2.3.4 The PSU system Device 2 I²C 7 bit address shall be 0x4A.

3 Message Content Requirements

3.1 Measured Values

3.1.1 The measured data fields for Device 1 and their associated ADS 7828 channels shall be as shown in Table 1.

Table 1

Field	Channel	Type	Min Value	Max Value	Description
-X PANEL V	0	Unsigned	0x00	0xFFFF	-X PANEL V
-Y PANEL V	1	Unsigned	0x00	0xFFFF	-Y PANEL V
-Z PANEL V	2	Unsigned	0x00	0xFFFF	-Z PANEL V
-X PANEL T	3	Unsigned	0x00	0xFFFF	-X PANEL T
-Y PANEL T	4	Unsigned	0x00	0xFFFF	-Y PANEL T
-Z PANEL T	5	Unsigned	0x00	0xFFFF	-Z PANEL T
Not used	6	-	-	-	-
Not used	7	-	-	-	-

3.1.2 The measured data fields for Device 2 and their associated ADS 7828 channels shall be as shown in Table 2.

Table 2

Field	Channel	Type	Min Value	Max Value	Description
+X PANEL V	0	Unsigned	0x00	0xFFFF	+X PANEL V
+Y PANEL V	1	Unsigned	0x00	0xFFFF	+Y PANEL V
+Z PANEL V	2	Unsigned	0x00	0xFFFF	+Z PANEL V
+X PANEL T	3	Unsigned	0x00	0xFFFF	+X PANEL T
+Y PANEL T	4	Unsigned	0x00	0xFFFF	+Y PANEL T
+Z PANEL T	5	Unsigned	0x00	0xFFFF	+Z PANEL T
PSU PCB Temperature	6	Unsigned	0x00	0xFFFF	Temperature of PSU card
Not used	7	-	-	-	-

3.1.3 Measurements shall be made in relation to the 2.5 VDC internal voltage reference for both ADS 7828 Devices.

3.1.4 For each Device the IHU shall poll each channel in channel number order.

Date: September 17, 2013

Version: Version 2.03

AMSAT Fox-1

IHU to Battery Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Battery (BATT1) System, as required per the AMSAT Fox-1 System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
August 7, 2012	1.00	Initial version
November 7, 2012	1.01	Added BATT CPU Temperature
December 27, 2012	1.10	Add Battery Groups Temperature, change from Bytes to Bits in Message Header Block, Message Data Block, Message Data
January 2, 2013	1.11	Field sizes back to bytes account I ² C specifications
February 7, 2013	1.12	Fix typo on 3.3.1.1
August 13, 2013	2.00	Updated for TI ADS 7828 replacing STM32L, straight I2C query/answer from IHU now for 8 channels of data.
August 22, 2013	2.01	Correct Battery Pair Temperature nomenclature
August 22, 2013	2.02	Update I ² C speed to 10 kHz
September 17, 2013	2.03	Fix formatting error that hid requirement 2.2.2, change type format to exclude code type, add Min/Max Values

1.2 Document Scope

The purpose of this document is to specify the message format and the I²C bus hardware operation for the communications between the IHU and the BATT1 as described in the AMSAT Fox-1 System Requirements Specification.

1.3 References

1. AMSAT Fox-1, System Requirements Specification
2. AMSAT Fox-1, System Design Specification
3. AMSAT Fox-1, IHU Software Architecture Specification
4. Texas Instruments SBAS181C – NOVEMBER 2001 - REVISED MARCH 2005

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The BATT1 shall be the I²C Slave.

2.1.2.1 The IHU shall request the BATT1 to send the data for a specific channel.

2.1.2.2 The BATT1 shall send that specific channel data.

2.1.3 The IHU shall test for the presence of the BATT1 system.

2.1.3.1 If the presence of the BATT1 system is not detected, the IHU shall not poll the system for data.

2.2 General Message Requirements

2.2.1 The IHU shall sample data at a rate sufficient to provide downlink telemetry data at least every 15 seconds.

2.2.2 The ADS 7820 A/D converter shall always be commanded on (PD-0 bit = 1).

2.2.3 The ADS 7820 Internal Reference shall always be commanded on (PD-1 bit = 1).

2.2.4 The ADS 7820 shall always be commanded for single-ended inputs.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Standard (10 kHz).

2.3.3 The BATT1 I²C 7 bit address shall be 0x48.

3 Data Requirements

3.1 Measured Values

3.1.1 The measured data fields and their associated ADS 7828 channels shall be as shown in Table 1.

Table 1

Field	Channel	Type	Min Value	Max Value	Description
BATT I	0	Unsigned	0x00	0xFFFF	Battery current raw value
BATT A V	1	Unsigned	0x00	0xFFFF	Battery pair A voltage raw value
BATT B V	2	Unsigned	0x00	0xFFFF	Battery pair B voltage raw value
BATT C V	3	Unsigned	0x00	0xFFFF	Battery pair C voltage raw value
BATT A T	4	Unsigned	0x00	0xFFFF	Battery pair A temperature raw value
BATT B T	5	Unsigned	0x00	0xFFFF	Battery pair B temperature raw value
BATT C T	6	Unsigned	0x00	0xFFFF	Battery pair C temperature raw value
BATT PCB Temperature	7	Unsigned	0x00	0xFFFF	Temperature of BATT card

3.1.2 Measurements shall be in relation to the 2.5 VDC internal voltage reference of the ADS 7828.

3.1.3 The IHU shall poll each channel in channel number order.

Date: September 17, 2013

Version: Version 1.06

AMSAT Fox-1A

IHU to Experiment 1 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 1 of the satellite, known as the Vanderbilt University Vulcan Payload and abbreviated herein as EXP1.

1.1 Document History

DATE	VERSION	SUMMARY
March 3, 2013	1.00	Initial version
March 7, 2013	1.01	Correct use of I ² C (1.2) and EXP1 (2.3.3)
March 31, 2013	1.02	Command Message CRC8 to include address byte, change to commands, modified figure 3, deleted figure 4
March 31, 2013	1.03	Delete TYPE from message tables, add SET TIME response return values
March 31, 2013	1.04	Add CMD_VERSION_ERR to Error Code table
April 2, 2013	1.05	Correct 6.5 Figure 3, remove 0x0005, 0x0201, 0x0210, 0x0281, 0x0300, and 0x0301 commands
September 17, 2013	1.06	Change type format to exclude code type, add Min/Max Values

1.2 Document Scope

This document will specify the control of EXP1, the messaging format, and the I²C bus hardware operation for the communications between the IHU and the EXP1.

1.3 References

1. AMSAT Fox-1, System Requirements Specification
2. AMSAT Fox-1, System Design Specification
3. AMSAT Fox-1, IHU Software Architecture Specification
4. Vanderbilt University Vulcan Payload Interface Control Document

2 General Messaging Requirements

2.1 Link Protocol Requirements

- 2.1.1 The IHU shall initiate a command to the EXP1.
- 2.1.2 The EXP1 shall send a reply to each IHU request.
- 2.1.3 Message bit order shall be Big Endian.
- 2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP1.
- 2.1.5 The EXP1 shall take no action in the event of an invalid or improper message from the IHU.
- 2.1.6 Message byte order shall be Big Endian.

2.2 General Message Requirements

- 2.2.1 Each message shall contain a header block.
- 2.2.2 Each message shall contain a packet error check (PEC) in the form of CRC8.
 - 2.2.2.1 The message address byte shall be included when calculating the CRC8.

2.3 I²C 1 Bus Hardware Interface Requirements

- 2.3.1 The I²C Vdd shall be 3.0V.
- 2.3.2 The bus speed shall be Fast (400kbit/s).
- 2.3.3 The EXP1 I²C 7 bit address shall be 0x2A.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP1 by the Experiment Enable 1 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low	Power Off Experiment

3.2 Experiment Power On Sequence

3.2.1 The IHU shall set and hold the Experiment Enable 1 pin HIGH.

3.2.2 The IHU shall not send any message to the EXP1 for a minimum of 100 milliseconds.

3.2.3 The IHU shall send a Set Time command to the EXP1.

3.3 Experiment Begin Operation Sequence

3.3.1 Upon completion of the Power On sequence the IHU shall send a Set Run State Active command message to the EXP1.

3.4 Experiment Cease Operation Sequence

3.4.1 The IHU shall send a Set Run State Halt command message to the EXP1.

3.4.2 The IHU shall not send any message to the EXP1 for a minimum of 10000 milliseconds.

3.4.3 The IHU shall send a Set Run State Standby command message to the EXP1.

3.5 Experiment Power Off Sequence

3.5.1 The IHU shall set and hold the Experiment Enable 1 pin LOW.

4 Message Content Requirements

4.1 Command Message

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command and Response block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP1 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Unsigned	0x0000	0x0280	Hexadecimal Command
ARGUMENT	Variable	Unsigned	-	-	Optional Arguments As Required

The command message block shall contain one command in the COMMAND COMMAND field as shown in Table 4.

Table 4

Command Name	Size (Bytes)	Type	Min Value	Max Value	Description
Nop	2	Unsigned	0x0000	0x0000	No effect; response undefined. Test for I ² C acknowledgement only.
Echo	2	Unsigned	0x0001	0x0001	Echo this byte stream
Resend	2	Unsigned	0x0002	0x0002	Resend last result
Get UID	2	Unsigned	0x0003	0x0003	Controller 7 byte identifier
Get Status	2	Unsigned	0x0004	0x0004	Controller status indication
Get Diagnostics	2	Unsigned	0x0006	0x0006	Self-check Diagnostic
Get Telemetry	2	Unsigned	0x0010	0x0010	Send telemetry data
Set Run State	2	Unsigned	0x0080	0x0080	Enter specified Run State
Get Run State	2	Unsigned	0x0081	0x0081	Query current Run State
Set Time	2	Unsigned	0x0100	0x0100	Number of seconds since epoch
Get Time	2	Unsigned	0x0101	0x0101	Number of seconds since epoch
Get Data	2	Unsigned	0x0280	0x0280	Send (number of bytes) data

4.2.3 The command message shall contain arguments for the Echo command, as shown in Table 5.

Table 5

Field	Size (Bytes)	Type	Min Value	Max Value	Description
ARGUMENT	4	Unsigned	-	-	Data to be echoed

4.2.4 The command message shall contain one argument for the Set Run State command, as shown in Table 6.

Table 6

Run State	Size (Bytes)	Type	Min Value	Max Value	Description
STANDBY	2	Unsigned	0x0001	0x0001	Enter Standby State
ACTIVE	2	Unsigned	0x0003	0x0003	Activate Experiments
HALT	2	Unsigned	0x0004	0x0004	Terminate Experiments

4.2.5 The command message shall contain arguments for the Set Time command, as shown in Table 7.

Table 7

Argument	Size (Bytes)	Type	Min Value	Max Value	Description
IHU Reset Counter	16	Unsigned	0x00	-	Count of the number of IHU resets from non-volatile FRAM
MET Timestamp	32	Unsigned	-	-	MET timestamp (seconds since last IHU reset)

4.2.6 The command message shall contain arguments for the Get Data command, as shown in Table 8.

Table 8

Argument	Size (Bytes)	Type	Min Value	Max Value	Description
BYTES TO SEND	2	Unsigned	0x00	0xFFFF	Number of bytes to send (1-256)

4.3 Response Message Block

4.3.1 The response message block shall be constructed as shown in Table 9.

Table 9

Field	Size (Bytes)	Type	Min Value	Max Value	Description
RESERVED	1	Unsigned	-	-	Reserved, ignore
ERROR CODE	1	Unsigned	0x0000	0x0006	Response to Command
LENGTH	2	Unsigned	0x00	0xFFFF	Length of Return Value in Bytes
RETURN VALUE	Variable	Variable	-	-	Return Value

4.3.2 The Error Code shall contain one code as shown in table 10.

Table 10

Name	Size (Bytes)	Type	Min Value	Max Value	Description
CMD_OK	1	Unsigned	0x0000	0x0000	Command invoked successfully
CMD_OP_ERR	1	Unsigned	0x0001	0x0001	Command not recognized
CMD_FORMAT_ERR	1	Unsigned	0x0002	0x0002	Incorrect command argument length
CMD_RANGE_ERR	1	Unsigned	0x0003	0x0003	Argument(s) out of bounds
CMD_PEC_ERR	1	Unsigned	0x0004	0x0004	Error check (CRC) mismatch
CMD_EXEC_ERR	1	Unsigned	0x0005	0x0005	Execution error
CMD_VERSION_ERR	1	Unsigned	0x0006	0x0006	Header Message Version mismatch

4.3.3 The Status Flags for a GET STATUS response message shall be represented as individual bit values of a 16 bit RETURN VALUE as shown in Table 11.

Table 11

Name	Bit Number	Description
REBOOTED	0	1 = Experiment has rebooted – NOT USED
DATA READY	1	1 = Experiment data available
TIME REQUEST	2	1 = Request SET TIME
FAILED RUN STATE	3	1 = Failed the run state – NOT USED
COMPLETED RUN STATE	4	1 = Completed the run state – NOT USED
RESERVED	5-15	Always 0

4.3.4 The response message to a Set Time command shall contain one of the values as shown in Table 12.

Table 12

Response Name	Size (Bytes)	Type	Min Value	Max Value	Description
SUCCESS	2	Signed	0x00	0x00	Time Set successfully
FAILURE	2	Signed	0xFFFF	0xFFFF	Time Set failed

5 Message Integrity

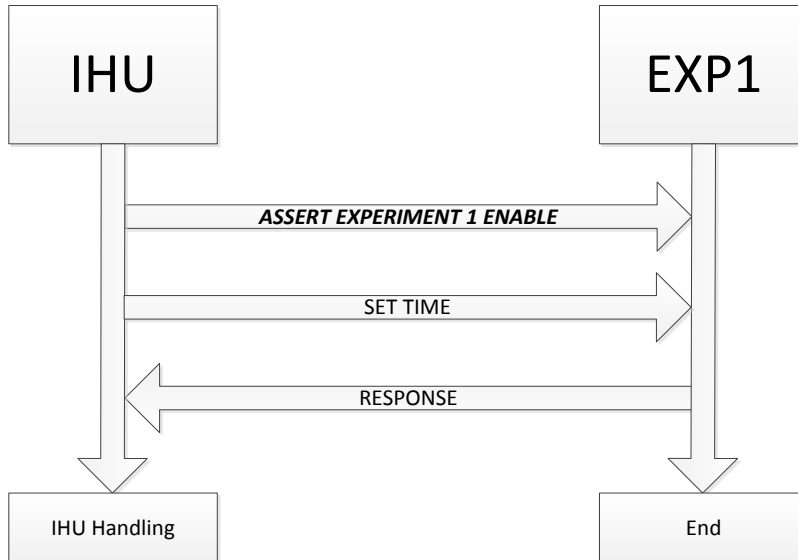
5.1 Invalid Messages

5.1.1 If the PEC (CRC8) fails, the message shall be considered invalid.

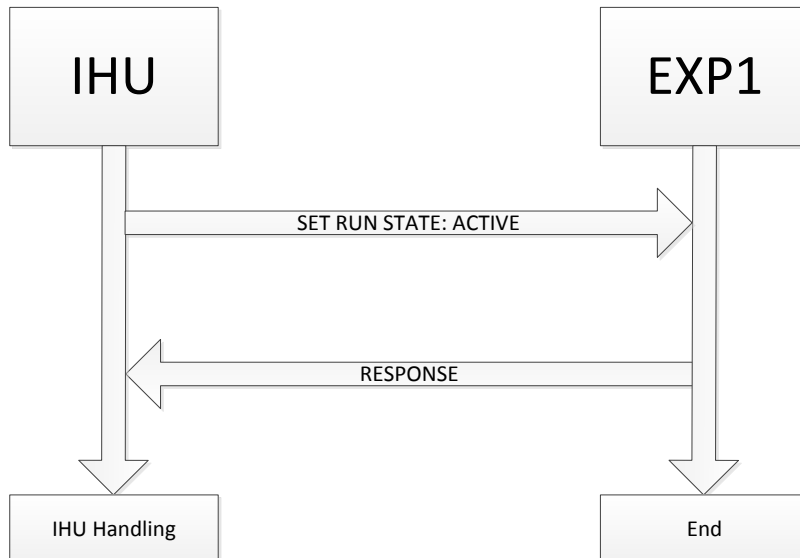
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

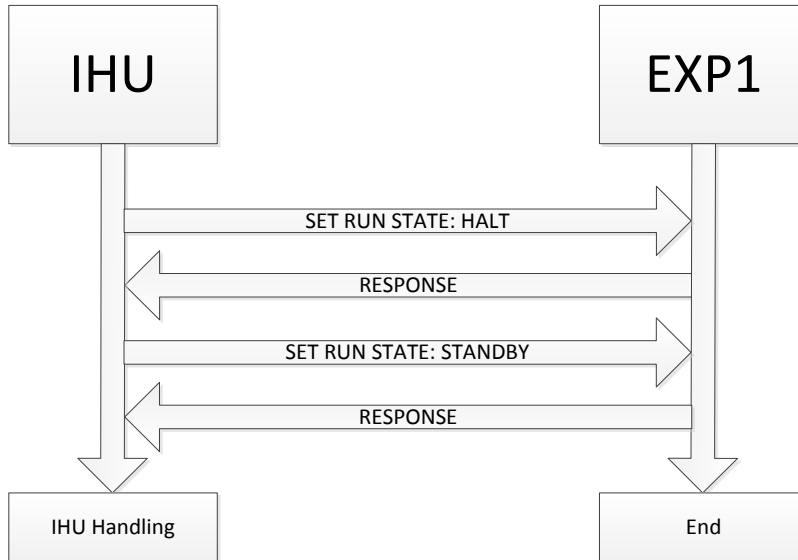
6.1 EXPERIMENT POWER ON SEQUENCE



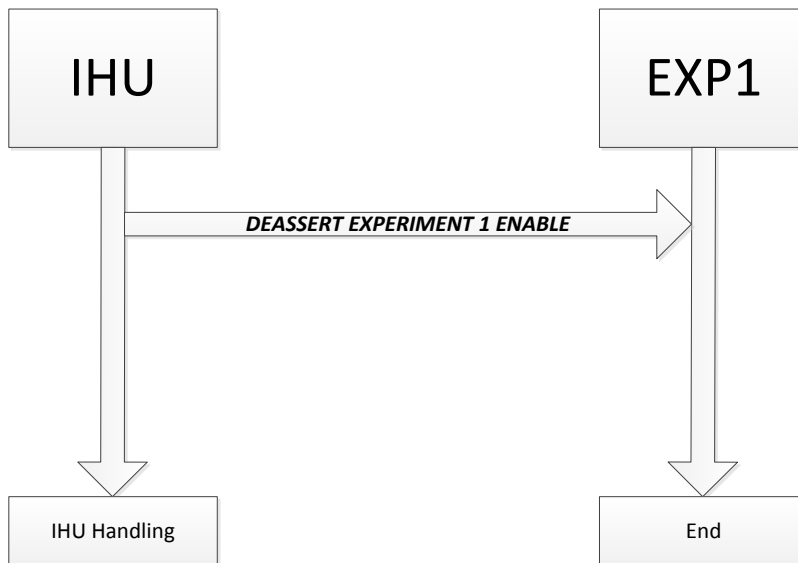
6.2 EXPERIMENT BEGIN OPERATION SEQUENCE



6.3 EXPERIMENT CEASE OPERATION SEQUENCE



6.4 EXPERIMENT POWER OFF SEQUENCE



6.5 SERVICING EXPERIMENT OPERATION

Figure 1

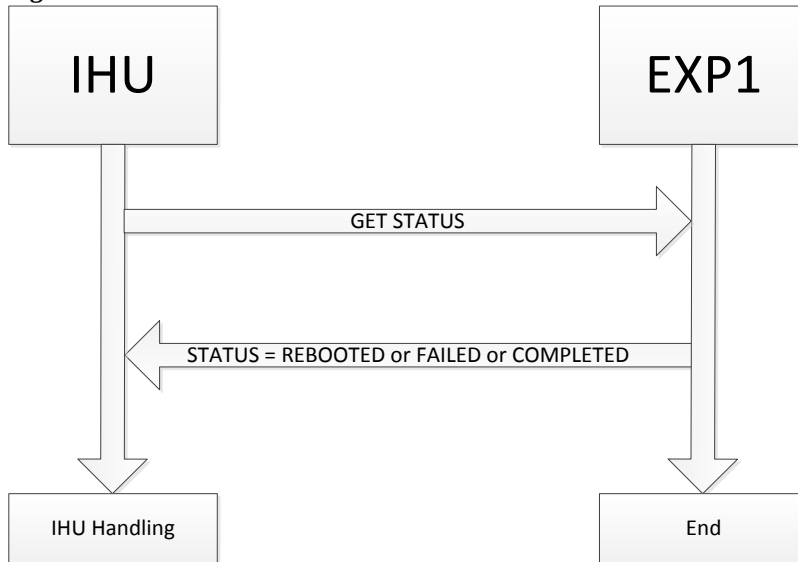


Figure 2

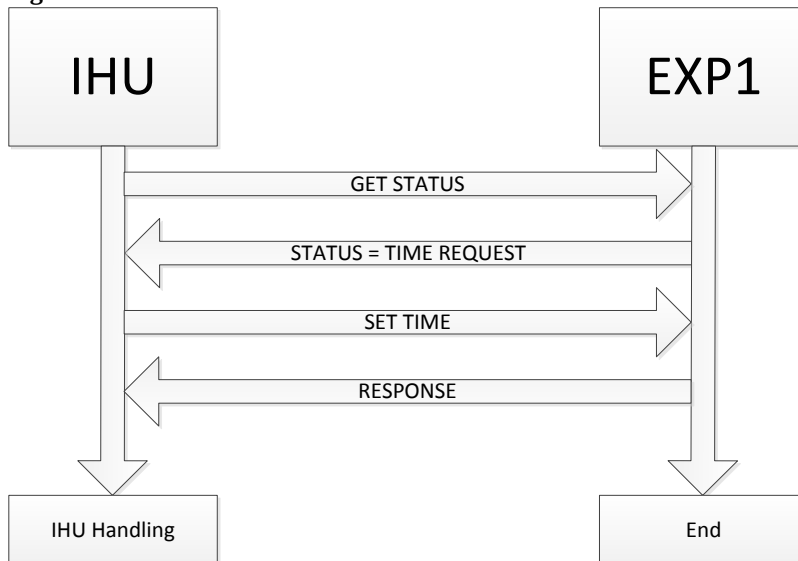
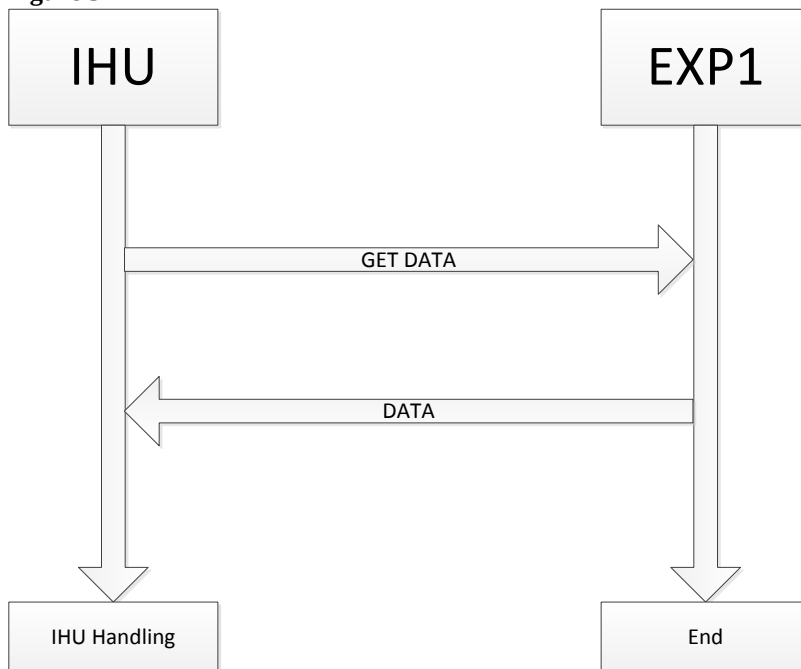


Figure 3



Date: October 4, 2013

Version: Version 1.11

AMSAT *Fox-1A*

IHU to Experiment 4 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 4 of the satellite, known as the VT Camera Experiment and abbreviated herein as EXP4.

1.1 Document History

DATE	VERSION	SUMMARY
January 24, 2013	1.00	Initial version
February 20, 2013	1.01	Specify byte order as little endian
May 21, 2013	1.10	Update data TYPE names
October 4, 2013	1.11	Change type format to exclude code type, add Min/Max Values, add thermistor circuit

1.2 Document Scope

This document will specify the control of EXP4, the messaging format, and the serial bus hardware operation for the communications between the IHU and the EXP4.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

- 2.1.1 The IHU shall initiate a command to the EXP4.
- 2.1.2 The EXP4 shall send a reply to each IHU request.
- 2.1.3 Message bit order shall be Little Endian.
- 2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP4.
- 2.1.5 The EXP4 shall take no action in the event of an invalid or improper message from the IHU.
- 2.1.6 Message byte order shall be Little Endian.

2.2 General Message Requirements

- 2.2.1 Each message shall contain a header block.
- 2.2.2 Each message shall contain one command, one reply, or one data block.

2.3 Serial Bus Hardware Interface Requirements

- 2.3.1 The bus levels shall be 3.0V.
- 2.3.2 The bus data speed shall be 38400 bit/s.
- 2.3.3 The serial bus communication shall be asynchronous.
- 2.3.4 The number of data bits shall be 8.
- 2.3.5 The number of stop bits shall be 1.
- 2.3.6 There shall be no parity bit.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP4 by the Experiment Enable 4 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low	Power Off Experiment

3.1.2 Upon signaling Power On to the EXP4, the IHU shall not send any message to the EXP4 for a minimum of 100 milliseconds.

3.2 Experiment Operation Sequence

3.2.1 Upon Power On the IHU shall determine the state of the EXP4 by sending an Is Camera Ready command message.

3.2.2 The IHU shall not send a Transmit Data Block command message prior to receiving a Camera Ready reply message from the EXP4.

4 Message Content Requirements

4.1 Message Header Block

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command, Reply, and Data block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP4 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Alpha	RR TT	RR TT	Command

4.2.2 The command message block shall contain one command in the COMMAND field as shown in Table 4.

Table 4

Command	Description
RR	Is Camera Ready?
TT	Transmit Data Block

4.3 Reply Message Block

4.3.1 The reply message block shall be constructed as shown in Table 5.

Table 5

Field	Size (Bytes)	Type	Min Value	Max Value	Description
REPLY	2	Alpha	NN YY FF	NN YY FF	Reply

4.3.2 The reply message block shall contain one reply in the REPLY field as shown in table 6.

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IHU to Experiment 4 ICD



Table 6

Command	Description
NN	Camera Not Ready
YY	Camera Ready
FF	Camera Failed

4.4 Message Data Block

4.4.1 The message data block shall be constructed as shown in Table 7.

Table 7

Field	Size (Bytes)	Type	Min Value	Max Value	Description
DESCRIPTOR	2	Unsigned	-	-	Line ID and Payload Length
PAYLOAD	Variable	Unsigned	-	-	Array of (Payload Length) bytes
CHKSUM	2	Unsigned	-	-	16 bit accumulator sum of bytes in HEADER and PAYLOAD

4.4.2 The bits of the message data block DESCRIPTOR bytes shall be constructed as shown in Table 8.

Table 8

Field	Size (Bits)	Type	Min Value	Max Value	Description
Line ID	6	Unsigned	0x01	0x3C	640 x 8 pixel picture line number (1 is top, 60 is bottom)
Payload Length	10	Unsigned	0x01	0x3FF	Total number of bytes in PAYLOAD

4.4.2.1 The Line ID shall compose the 6 MSB and the Payload Length shall compose the 10 LSB.

5 Message Integrity

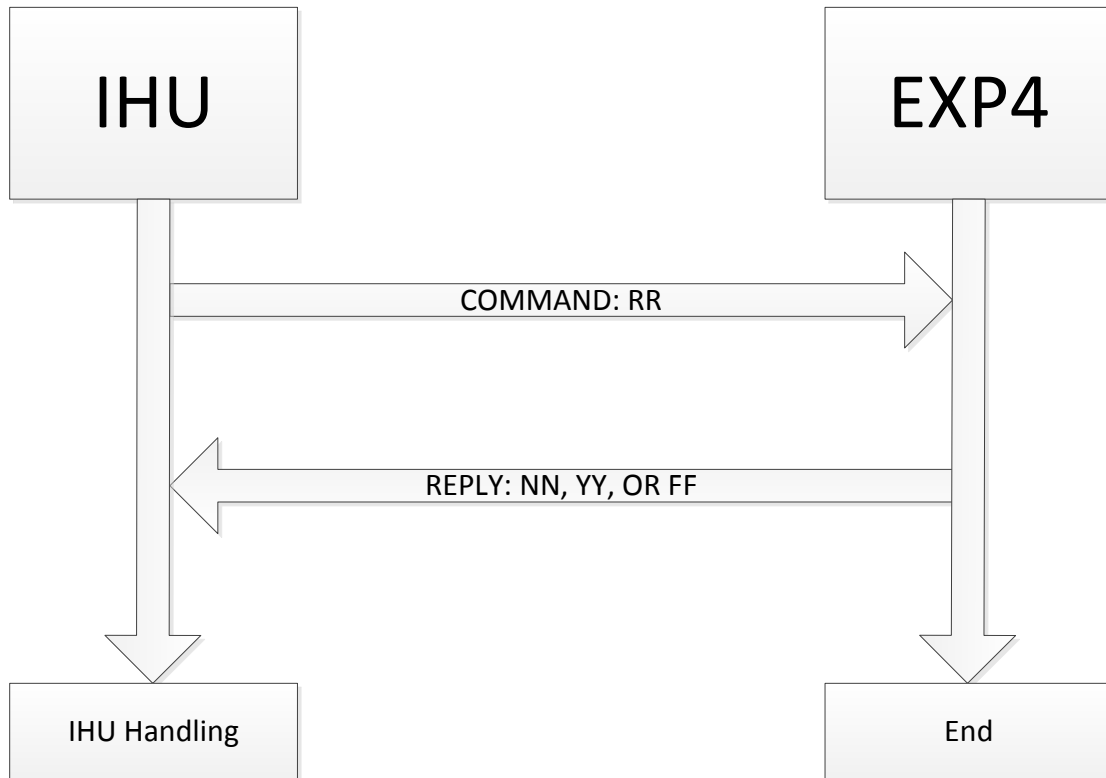
5.1 Invalid Messages

5.1.1 If the DATA block CHKSUM fails, the message shall be considered invalid.

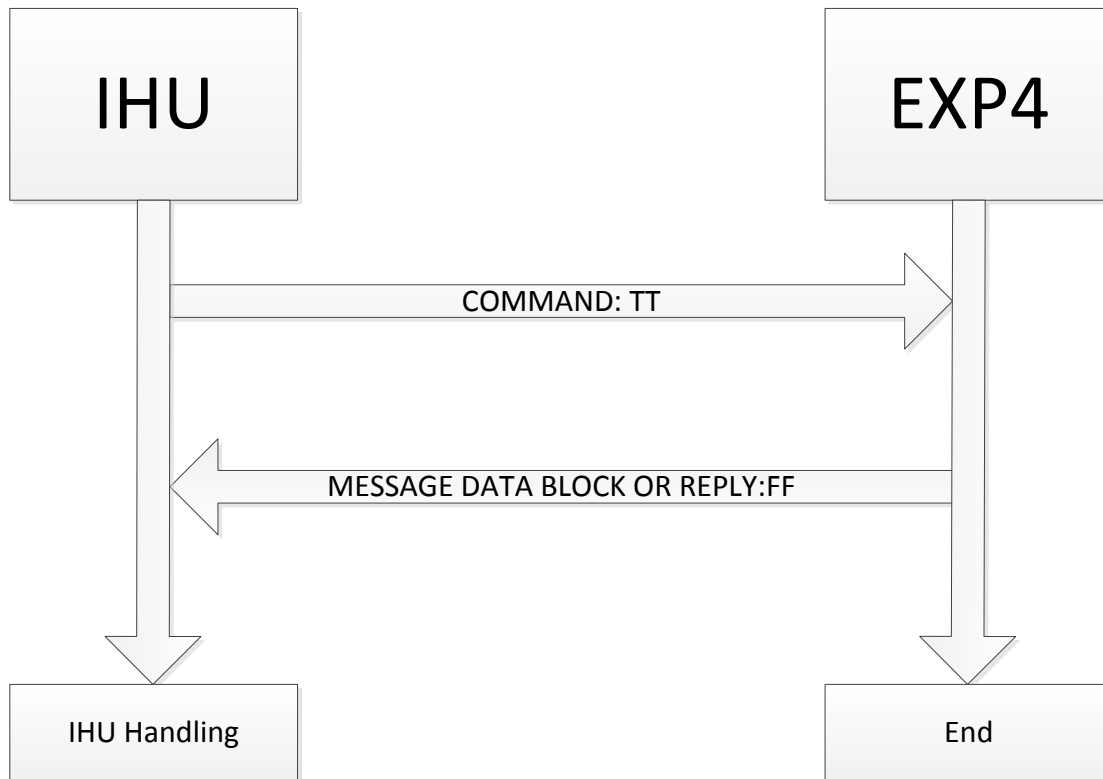
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

6.1 RR COMMAND



6.2 TT COMMAND



7 Experiment Card Temperature Telemetry

7.1 Thermistor

7.1.1 The experiment shall provide a DC voltage derived from a thermistor circuit mounted on the experiment card, to the IHU via the system bus.

7.1.2 The voltage shall be the raw voltage value of the thermistor circuit.

Note: AMSAT shall provide the schematic and BOM for the thermistor circuit.

Date: August 26, 2013
Version: Version 1.41

AMSAT Fox-1A

Downlink Specification

1 Introduction

This document specifies downlink frame formats for the Fox-1A telemetry and experiment telemetry. This specification includes the both slow and high speed formats.

Document History

DATE	VERSION	SUMMARY
April 25, 2013	1.01	Remove TX PA Temperature and TX Osc Temperature, add TX Temperature
May 21, 2013	1.2	High speed downlink details added
May 27, 2013	1.3	Remove Radiation Experiment Telemetry Frame, resize Radiation Experiment Data Frame, renumber Payload Types, added Slow Speed Link Layer Transmission Scheduling, changed Reset Count to 16 bits
June 6, 2013	1.31	Reduce BATT CPU, PSU CPU, IHU CPU, TX Temp, RX Osc Temp from 12 to 8 bit value, add IHU Error Data field to Telemetry Minimum Values Frame
June 26, 2013	1.32	Correct Payload Type numbers in Table 6
August 13, 2013	1.40	Changes due to new BATT telemetry values, delete Type 4 from idle telemetry
August 26, 2013	1.41	Change Receiver Osc Temperature to Receiver Card Temperature, remove TOTAL MPPT I, update 2.2.9.1 and 2.2.9.1.1 to reflect variable size of Radiation Experiment Data available

1.1 Document Scope

The purpose of this document is to specify the downlink protocol on the AMSAT Fox-1A spacecraft.

1.2 References

1. Fox1 IHU to RF ICD
2. Fox1 IHU to Battery ICD
3. Fox1 IHU to PSU ICD
4. Fox1 IHU to Attitude Determination Experiment ICD

5. Fox1 IHU Software Architecture Specification
6. Fox1 IHU to Experiment 1 ICD
7. Fox1 IHU to Experiment 4 ICD

1.3 Definitions

- 1.3.1 Slow Speed Downlink – Data transmitted at approximately 100 bits per second in the audio portion below 300 Hz simultaneous with the transponder audio.
- 1.3.2 High Speed Downlink – Data transmitted at approximately 9600 bits per second using the entire downlink audio passband.
- 1.3.3 Spacecraft Telemetry – Downlink data containing specific information about spacecraft systems and health as defined in the System Requirements and related documents.
- 1.3.4 Experiment Telemetry – Downlink data containing specific information about the various experiment platforms flown on the satellite.
- 1.3.5 Frame – A defined set of data with a specific overall size comprised of fields of a specific bit or byte length.

2 Protocol Structure

2.1 Physical Layer

2.1.1 The physical layer includes options for slow-speed and high speed operation.

2.1.2 Slow speed operation uses frequency-shift keying and is transmitted in the sub-audible part of the audio downlink below 300 Hz. It may be transmitted simultaneously with voice or other audio signals. The details of the physical layer are shown in Table 1.

Table 1

Bit Rate	100 bps
Scrambler	TBR
Spectral efficiency	1 bps/Hz
Modulation type	Non-coherent Frequency Shift Keying (FSK)
Signal bandwidth	10 Hz to 200 Hz (-3 dB points)
FSK Deviation	500 Hz
Spectral Mask	-20 dB at 300 Hz
RF Channel Bandwidth	1200 Hz

2.1.3 High speed operation uses frequency-shift keying and is transmitted using the entire RF downlink bandwidth. The details of the physical layer are shown in Table 2. *Note that this is the same as the G3RUH modem.*

Table 2

Bit Rate	9600 bps
Scrambler	17 bit maximal length LFSR
Spectral efficiency	2 bps/Hz
Modulation type	non-coherent frequency shift keying (FSK)
Signal bandwidth	10 Hz to 4800 Hz (-3 dB points)
FSK Deviation	3 kHz
Spectral Mask	-60 dB at 7500 Hz
RF Channel Bandwidth	20 kHz

2.2 Link Layer

2.2.1 The link layer protocol provides multiplexing, packet identification and forward error correction.

2.2.2 The link layer shall include a header and a trailer surrounding the applications layer payload to form data packets as shown in Table 3.

Table 3

Header	Applications Payload	Trailer
--------	----------------------	---------

2.2.3 The applications payload layer shall include satellite telemetry, experiment telemetry, high speed data, and debug frames.

2.2.4 Debug frames may be used during ground testing but shall not be transmitted for flight.

2.2.5 Bits shall be transmitted in the order of least significant bit first.

2.2.6 Bytes shall be transmitted in Little Endian order.

2.2.7 The Slow Speed link layer header structure shall be as shown in Table 4.

Table 4

Field	Size (Bits)	Type	Value	Description
Fox ID	3	Unsigned char	0x01	0x01 specifies Fox-1A (each Fox satellite will have a unique ID)
Reset Count	16	Unsigned short	Variable	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned int	Variable	This is the IHU uptime in seconds since the last reset
Type	4	Unsigned char	Variable	This identifies the payload type

2.2.7.1 Payload type shall be as specified in the application layer payload data.

2.2.7.2 Each Slow Speed link layer structure shall contain only one payload type.

2.2.8 The High Speed link layer header structure is shown in Table 5.

Table 5

Field	Size (Bits)	Type	Value	Description
Fox ID	3	Unsigned char	0x01	0x01 specifies Fox-1A (each Fox satellite will have a unique ID)
Reset Count	14	Unsigned short	Variable	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned int	Variable	This is the IHU uptime in seconds since the last reset

2.2.9 The High Speed link layer applications payload shall contain data from all payload types, as shown in table 6.

Table 6

Payload Type	Size (Bytes)	Description
1	60	Real-Time Telemetry Frame
2	60	Telemetry Maximum Values Frame
3	60	Telemetry Minimum Values Frame
5	Variable 1 - 4300	Camera JPEG Data Frame
4	58	Radiation Experiment High Speed Data Frame

2.2.9.1 A varying number of Radiation Experiment Data bytes shall be sent to fill the applications payload size to a total of 4600 bytes if the payload type 5 data is less than 4300 bytes.

2.2.9.1.1 When less than a sufficient number of bytes to contain a useful data frame remain to fill to 4600 bytes, the remaining bytes shall be filled with zeros.

2.2.9.2 Real-Time Telemetry Frame, Telemetry Maximum Values Frame, and Telemetry Minimum Values Frame data shall be padded with zeros to equal 60 bytes length each.

2.2.10 Forward error correction (FEC) code words shall be sent in the link layer trailer. The FEC shall be a Reed Solomon RS (TBR) code. (This provides TBR error detection and correction capability.)

3 Slow Speed Link Layer Transmission Scheduling

3.1 While IHU PTT is asserted Payload Types contained in the Link Layer Applications Payload shall rotate, changing type with each successive link layer transmitted, in the following order:

- Type 1
- Type 4
- Type 1
- Type 4
- Type 1
- Type 2
- Type 4
- Type 1
- Type 4
- Type 1
- Type 4
- Type 3

3.1.1 The above order shall be repeated so long as IHU PTT is asserted.

3.2 While beacon message is sent during idle timer expired the Payload Types contained in the Link Layer Applications Payload shall be transmitted only once in the following order:

- Type 1

4 Application Layer Payload Data

4.1 Payload Type 1 - Real-Time Telemetry Frame (Size = 334 bits)

Table 7

Field	Size (Bits)	Type	Value	Description
BATT A V	12	Unsigned short	Variable	Battery pair A voltage raw value
BATT B V	12	Unsigned short	Variable	Battery pair B voltage raw value
BATT C V	12	Unsigned short	Variable	Battery pair C voltage raw value
BATT A T	12	Unsigned short	Variable	Battery pair A temperature raw value
BATT B T	12	Unsigned short	Variable	Battery pair B temperature raw value
BATT C T	12	Unsigned short	Variable	Battery pair C temperature raw value
TOTAL BATT I	12	Signed short	Variable	Total Battery DC current raw value
BATT Board Temperature	8	Unsigned short	Variable	PC Board Temperature of BATT
+X PANEL V	12	Unsigned short	Variable	+X solar panel voltage raw value
-X PANEL V	12	Unsigned short	Variable	-X solar panel voltage raw value
+Y PANEL V	12	Unsigned short	Variable	+Y solar panel voltage raw value
-Y PANEL V	12	Unsigned short	Variable	-Y solar panel voltage raw value
+Z PANEL V	12	Unsigned short	Variable	+Z solar panel voltage raw value
-Z PANEL V	12	Unsigned short	Variable	-Z solar panel voltage raw value
+X PANEL T	12	Unsigned short	Variable	+X solar panel temperature raw value
-X PANEL T	12	Unsigned short	Variable	-X solar panel temperature raw value
+Y PANEL T	12	Unsigned short	Variable	+Y solar panel temperature raw value
-Y PANEL T	12	Unsigned short	Variable	-Y solar panel temperature raw value
+Z PANEL T	12	Unsigned short	Variable	+Z solar panel temperature raw value
- Z PANEL T	12	Unsigned short	Variable	-Z solar panel temperature raw value

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Field	Size (Bits)	Type	Value	Description
PSU CPU Temperature	8	Unsigned short	Variable	CPU Temperature of PSU
SPIN	12	Signed char	Variable	PSU calculated spin rate RPM
TX PA Current	12	Unsigned short	Variable	Transmit power amplifier current
TX Temperature	8	Unsigned short	Variable	Transmitter card temperature
RX Temperature	8	Unsigned short	Variable	Receiver card temperature
IHU CPU Temperature	8	Unsigned short	Variable	CPU Temperature of IHU
Antenna Deploy Sensors	2	2x Unsigned char: 1	Variable	Bit 0 is RCV Bit 1 is XMT 0 = stowed 1 = deployed
Satellite X Axis Angular Velocity	12	Unsigned short	Variable	Raw Angle
Satellite Y Axis Angular Velocity	12	Unsigned short	Variable	Raw Angle
Satellite Z Axis Angular Velocity	12	Unsigned short	Variable	Raw Angle
Experiment Failure Indication	4	4x Unsigned char: 1	Variable	Bit 0 is Experiment 1 Bit 1 is Experiment 2 (N/A on Fox-1A) Bit 2 is Experiment 3 (N/A on Fox-1A) Bit 3 is Experiment 4 State: 0 = Working, 1 = Failed

4.2 Payload Type 2 - Telemetry Maximum Values Frame (Size = 342 bits)

Table 8

Field	Size (Bits)	Type	Value	Description
BATT A V	12	Unsigned short	Variable	Battery pair A high voltage raw value
BATT B V	12	Unsigned short	Variable	Battery pair B high voltage raw value
BATT C V	12	Unsigned short	Variable	Battery pair C high voltage raw value
BATT A T	12	Unsigned short	Variable	Battery pair A high temperature raw value
BATT B T	12	Unsigned short	Variable	Battery pair B high temperature raw value
BATT C T	12	Unsigned short	Variable	Battery pair C high temperature raw value
TOTAL BATT I	12	Signed short	Variable	Battery DC high current raw value
BATT Board Temperature	8	Unsigned short	Variable	High PC Board Temperature of BATT
+X PANEL V	12	Unsigned short	Variable	+X solar panel high voltage raw value
-X PANEL V	12	Unsigned short	Variable	-X solar panel high voltage raw value
+Y PANEL V	12	Unsigned short	Variable	+Y solar panel high voltage raw value
-Y PANEL V	12	Unsigned short	Variable	-Y solar panel high voltage raw value
+Z PANEL V	12	Unsigned short	Variable	+Z solar panel high voltage raw value
-Z PANEL V	12	Unsigned short	Variable	-Z solar panel high voltage raw value
+X PANEL T	12	Unsigned short	Variable	+X solar panel high temperature raw value
-X PANEL T	12	Unsigned short	Variable	-X solar panel high temperature raw value
+Y PANEL T	12	Unsigned short	Variable	+Y solar panel high temperature raw value
-Y PANEL T	12	Unsigned short	Variable	-Y solar panel high temperature raw value
+Z PANEL T	12	Unsigned short	Variable	+Z solar panel high temperature raw value
- Z PANEL T	12	Unsigned short	Variable	-Z solar panel high temperature raw value

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Downlink Specification



Field	Size (Bits)	Type	Value	Description
PSU CPU Temperature	8	Unsigned short	Variable	High CPU Temperature of PSU
SPIN	12	Signed char	Variable	Highest PSU calculated spin rate
TX PA Current	12	Unsigned short	Variable	Transmit power amplifier high current
TX Temperature	8	Unsigned short	Variable	Transmitter card high temperature
RX Temperature	8	Unsigned short	Variable	Receiver card high temperature
IHU CPU Temperature	8	Unsigned short	Variable	High CPU Temperature of IHU
(No Value)	2	Unsigned char	Fixed	0x00 filler
Satellite X Axis Angular Velocity	12	Unsigned short	Variable	Highest Raw Angle
Satellite Y Axis Angular Velocity	12	Unsigned short	Variable	Highest Raw Angle
Satellite Z Axis Angular Velocity	12	Unsigned short	Variable	Highest Raw Angle
MRAM Error Count	12	Unsigned short	Variable	Total MRAM Errors

4.3 Payload Type 3 - Telemetry Minimum Values Frame (Size = 362 bits)

Table 9

Field	Size (Bits)	Type	Value	Description
BATT A V	12	Unsigned short	Variable	Battery pair A low voltage raw value
BATT B V	12	Unsigned short	Variable	Battery pair B low voltage raw value
BATT C V	12	Unsigned short	Variable	Battery pair C low voltage raw value
BATT A T	12	Unsigned short	Variable	Battery pair A low temperature raw value
BATT B T	12	Unsigned short	Variable	Battery pair B low temperature raw value
BATT C T	12	Unsigned short	Variable	Battery pair C low temperature raw value
TOTAL BATT I	12	Signed short	Variable	Battery DC low current raw value
BATT Board Temperature	8	Unsigned short	Variable	High PC Board Temperature of BATT
+X PANEL V	12	Unsigned short	Variable	+X solar panel low voltage raw value
-X PANEL V	12	Unsigned short	Variable	-X solar panel low voltage raw value
+Y PANEL V	12	Unsigned short	Variable	+Y solar panel low voltage raw value
-Y PANEL V	12	Unsigned short	Variable	-Y solar panel low voltage raw value
+Z PANEL V	12	Unsigned short	Variable	+Z solar panel low voltage raw value
-Z PANEL V	12	Unsigned short	Variable	-Z solar panel low voltage raw value
+X PANEL T	12	Unsigned short	Variable	+X solar panel low temperature raw value
-X PANEL T	12	Unsigned short	Variable	-X solar panel low temperature raw value
+Y PANEL T	12	Unsigned short	Variable	+Y solar panel low temperature raw value
-Y PANEL T	12	Unsigned short	Variable	-Y solar panel low temperature raw value
+Z PANEL T	12	Unsigned short	Variable	+Z solar panel low temperature raw value
- Z PANEL T	12	Unsigned short	Variable	-Z solar panel low temperature raw value

AMSAT Fox-1A
Downlink Specification



Field	Size (Bits)	Type	Value	Description
PSU CPU Temperature	8	Unsigned short	Variable	Low CPU Temperature of PSU
SPIN	12	Signed char	Variable	Lowest PSU calculated spin rate
TX PA Current	12	Unsigned short	Variable	Transmit power amplifier low current
TX Temperature	8	Unsigned short	Variable	Transmitter card low temperature
RX Temperature	8	Unsigned short	Variable	Receiver card low temperature
IHU CPU Temperature	8	Unsigned short	Variable	Low CPU Temperature of IHU
(No Value)	2	Unsigned char	Fixed	0x00 filler
Satellite X Axis Angular Velocity	12	Unsigned short	Variable	Lowest Raw Angle
Satellite Y Axis Angular Velocity	12	Unsigned short	Variable	Lowest Raw Angle
Satellite Z Axis Angular Velocity	12	Unsigned short	Variable	Lowest Raw Angle
IHU Error Data	20	Unsigned int	Variable	Data on Last IHU Error

4.4 Payload Type 4 - Radiation Experiment Data Frame (Size = 464 bits)

Table 10

Field	Size (Bytes)	Value	Description
Data	58	Variable	Experiment 1 Packets

4.5 Payload Type 5 - Camera JPEG Data Frame (Size is variable)

Table 11

Field	Size (Bytes)	Type	Value	Description
Picture Lines	4300	Unsigned int	Variable	Picture Data ¹

¹ See section 4 for Picture Data Structure

5 Picture Data Structure

5.1 Scan Line Segment

Table 12

Field	Size (Bits)	Type	Value	Description
Picture Counter	4	Unsigned char	Variable	0x00 through 0x0F, picture count indicator
Scan Line Number	5	Unsigned char	Variable	0x00 through 0x3B, 0x00 = top scan line
Scan Line Length	10	Unsigned short	Variable	0x001 through 0x3FF, count of bytes in the scan line
Scan Line Data	Variable	Unsigned int	Variable	(Fragment Length) Scan Line Data
End of JPEG Data	8	Unsigned char	0xAA	Indicates end of Picture Data for use in Applications Payload construction

5.1.1 Total Scan Line Segment data size for one Applications Payload frame including end of JPEG data indicator byte shall not exceed 4300 bytes.

Date: January 1, 2013
Version: *draft H*

AMSAT Fox-1

IHU Software Architecture Specification

1 Introduction

This software architecture document is a specification of the desired behavior of the IHU software and guidance on an overall structure for the implementation.

1.1 Document History

DATE	VERSION	SUMMARY

1.2 Document Notes

Process specifications are described in this document using a "C-like" psuedocode syntax. This is intended as high-level descriptions of the procedures and not compilable code.

1.3 References

1. Concept of Operations, Version 1.03, OCT 19, 2011
2. System Requirements Specification, Version 1.2, OCT 17, 2012
3. IHU to Battery Interface Control Document, Version 1.01, November 7, 2012
4. IHU to PSU Interface Control Document, Version 1.04, November 7, 2012
5. Radiation Experiment Interface Control Document ???
6. Camera Interface Control Document ??
7. Downlink Protocol Specification ???

2 Processing Environment

2.1 Microcontroller

The IHU software will run on an STMicroelectronics STM32L151VBT microcontroller. The CPU is an ARM® Cortex™-M3 processor with a maximum clock speed of 32 MHz. This is a 32-bit processor and it provides up to 33 MIPS of processing power. The microcontroller includes 128K bytes of FLASH program memory, 4K bytes of non-volatile EEPROM and 16K bytes of RAM.

2.2 MRAM

The IHU card includes an Everspin Technologies MR25H10 MRAM. This is a 128K byte, non-volatile, read-write memory. The MR25H10 is highly tolerant of space radiation and is expected to be error-free during on-orbit operation. However, it is connected to the microcontroller through an SPI bus interface which may be sensitive to space radiation effects. Therefore, as a minimum, a single-bit-error detection scheme should be used to detect errors that might be induced during SPI transfers. This can be easily accommodated with a 16-bit checksum of 8-bit bytes for each data structure stored in the memory. Writes to the MRAM should be immediately followed by a read-verify operation to insure that the write was successful. A retry scheme should be used to handle detected errors.

2.3 MicroSD Card

The IHU has the capability of hosting a microSD FLASH memory card. This is not expected to be used for the initial *Fox-1* satellite mission but is available for software development if desired.

2.4 I/O Interfaces

The IHU microcontroller includes the following types of on-chip I/O interfaces:

Type	Description
A/D	Analog to Digital Converter (input)
D/A	Digital to Analog Converter (output)
I2C	I2C bus
GPI	General Purpose IO (used as input)
GPO	General Purpose IO (used as output)
Serial-I	Asynchronous serial input
Serial-O	Asynchronous serial output
SPI	SPI Bus

The above "Type" codes are used in the next section to indicate how peripheral device signals are interfaced with the IHU microcontroller.

3 Peripheral Devices

This section describes the IHU peripherals and their interfaces to the microcontroller. See the IHU card documentation for the specific port and pin information. *It would probably be very helpful to create a cross-reference between the Fox-1 bus signals and the STM32 port/pins.*

3.1 MEMS Gyroscopes

The IHU card includes a pair of STMicroelectronics, LPY403AL, 2-axis MEMS gyroscopes. They are physically arranged so that 3-axis of angular velocity can be measured. The GPIO outputs on the microcontroller are used to control the operation of the gyros and the gyro outputs drive A/D inputs on the microcontroller.

The interface is as follows:

Name	Type
Gyro HP	GPO
Gyro ST	GPO
Gyro_Vref_1	A/D
Gyro_Vref_2	A/D
Gyro_X_1	A/D
Gyro_Z_1	A/D
Gyro_X_2	A/D
Gyro_Z_2	A/D

Note that the Gyro_Z_2 channel provides duplicate information and is not used.

Looking down at the top (+Z) of the satellite, a Gyro_Z_1 voltage above the Gyro_Vref_1 voltage indicates a counter-clockwise rotation about the satellite's Z axis.

Looking straight at the +Y solar panel of the satellite, a Gyro_X_1 voltage above the Gyro_Vref_1 voltage indicates a counter-clockwise rotation about the satellite's Y axis.

Looking straight at the +X solar panel of the satellite, a Gyro_X_2 voltage above the Gyro_Vref_2 voltage indicates a **clockwise** rotation about the satellite's X axis. This is opposite from the other axis and must be multiplied by -1 to be consistent when reported.

Refer to the LPY403AL spec sheet to understand how to test (for diagnostics) and operate the MEMS gyro devices.

3.2 Antenna Deployer Control

These signals activate the antenna deployment mechanisms and sense the deployment status. The precise sequencing and operation of these signals is TBD.

Name	Type
TX Antenna Sensor	GPI
RX Antenna Sensor	GPI
TX Antenna Deploy	GPO
RX Antenna Deploy	GPO

3.3 Radio Control

These are the signals used to operate the RF up and down links.

Name	Type
Command Mode	GPO
IHU_PTT	GPO
IHU_Audio_1_Out	D/A
IHU_Audio_2_Out *	D/A
RX_CD *	GPI
RX_PTT *	GPI
Rx_Audio_1	A/D
Rx_Audio_2 *	A/D

* For *Fox-1*, the IHU_Audio_2_Out, RX_CD, RX_PTT and Rx_Audio_2 signals are not used by the IHU software.

3.4 IHU Card Telemetry

These are the telemetry parameters from sensors on the IHU card.

Name	Type
IHU CPU Temperature	A/D

3.5 External Watchdog Timer

In addition to the STM32 internal watchdog timer, the IHU card has an external watchdog timer. The IHU software must pulse the "Watchdog" lead at least once per second. Failure to do this will cause the IHU to be power-cycled.

Name	Type
Watchdog	GPO

3.6 Hardware Command Decoder

There is a 4-bit, hardware command decoder on the RF Rx card. The 4 output bits and a data valid strobe are available on the IHU card on GPIO leads. The decoder output bits 8-11 are latched. The data valid strobe is a rising edge and is not latched. At satellite power up, all signals will be 0.

Output	Type
RX Command Data11	GPI
RX Command Data10	GPI
RX Command Data9	GPI
RX Command Data8	GPI
RX Command Strobe	GPI

The most significant bit (Data 11) is used to inhibit the RF transmitter. The second most significant bit (Data 10) is used to inhibit the IHU (i.e. power off.) These are implemented in hardware and operate without any software intervention. The commands are coded as follows:

Bit Pattern	Command
1xxx	Inhibit TX
0xxx	Enable TX
x1xx	Inhibit IHU (power off)
x0xx	Enable IHU (power on)
xx00	Go To Transponder Mode
xx01	Go To Data Mode
xx10	Clear Telemetry Min/Max data
xx11	Send Test Message

3.7 RF System Telemetry

These are analog sensors on the RF cards that feed A/D inputs on the STM32.

Parameter	Type
TX PA Current	A/D
TX PA Temperature	A/D
TX Osc Temperature	A/D
RX Osc Temperature	A/D

3.8 Battery Card Telemetry

These data elements come from the Battery card via an I2C interface that is shared with the PSU card. See the IHU to Battery Interface Control Document for more details.

Parameter
Battery Cell 1 Volts
Battery Cell 2 Volts
Battery Cell 3 Volts
Battery Cell 4 Volts
Battery Cell 5 Volts
Battery Cell 6 Volts
Battery Pair 1 Temperature
Battery Pair 2 Temperature
Battery Pair 3 Temperature
Battery Card Current*
BAT CPU Temperature

*Note: Total current into (charge) or out of (discharge) the card.

3.9 PSU Card Telemetry

These parameters come from the PSU card via an I2C interface that is shared with the Battery card. See the IHU to PSU Interface Control Document for more details.

Parameter
+X Solar Panel Volts
-X Solar Panel Volts
+Y Solar Panel Volts
-Y Solar Panel Volts
+Z Solar Panel Volts
-Z Solar Panel Volts
+X Solar Panel Temperature
-X Solar Panel Temperature
+Y Solar Panel Temperature
-Y Solar Panel Temperature
+Z Solar Panel Temperature
-Z Solar Panel Temperature
Satellite Spin Rate*
Total Output Current
PSU CPU Temperature

*Note: the satellite spin rate is calculated on the PSU card from the solar panel voltages and is only meaningful when the satellite is in sunlight.

3.10 USB Umbilical Port

The umbilical port is functionally a USB port. The USB port can provide power to the satellite avionics and can be used to charge the satellite batteries. Since battery charging will exceed the standard USB current capability, a special power adapter will be used when charging the batteries. A GPIO input lead will indicate that the USB port is providing power to the satellite.

To the USB host, the satellite will look like a COM port and will allow use of the standard host USB COM driver. The intention is that the satellite can be easily used with common terminal emulation programs such as PuTTY. This port is used by the Diagnostics Subsystem that is described later in the document.

3.11 Debug Port

This is a serial port available for SW development use. It is not needed or used for the mission. It is expected that a call to a debug "printf()" would direct the output string to the debug port. It is expected this port would use asynchronous ASCII 8 Data bits, no parity, 1 stop bit, 19.2 k bps. As an alternative, the Umbilical port could be enhanced to display software debug messages rather than use a dedicated serial port. This port could be used for a debugger such as GDB if desired.

3.12 Radiation Experiment

Power to the radiation experiment cards is controlled via a GPIO output that drives the "Experiment Enable 1" bus signal.

An I2C bus is used to get the radiation experiment data. The specifics of this interface are defined in the *Fox-1* Experiment Interface Control Document.

3.13 Camera

Power to the camera card is controlled via a GPIO output that drives the "Experiment Enable 4" bus signal.

A serial port is used to send commands to the camera and to get the camera image data. The specifics of this interface are defined in the *Fox-1* Camera Interface Control Document.

4 CPU Start Up Sequence

This is the sequence of events after a CPU reset or at power up.

```
// Run Power On Self Test (POST)
// Check the program FLASH and run a CPU test
// Remember to pulse the external watchdog timer!

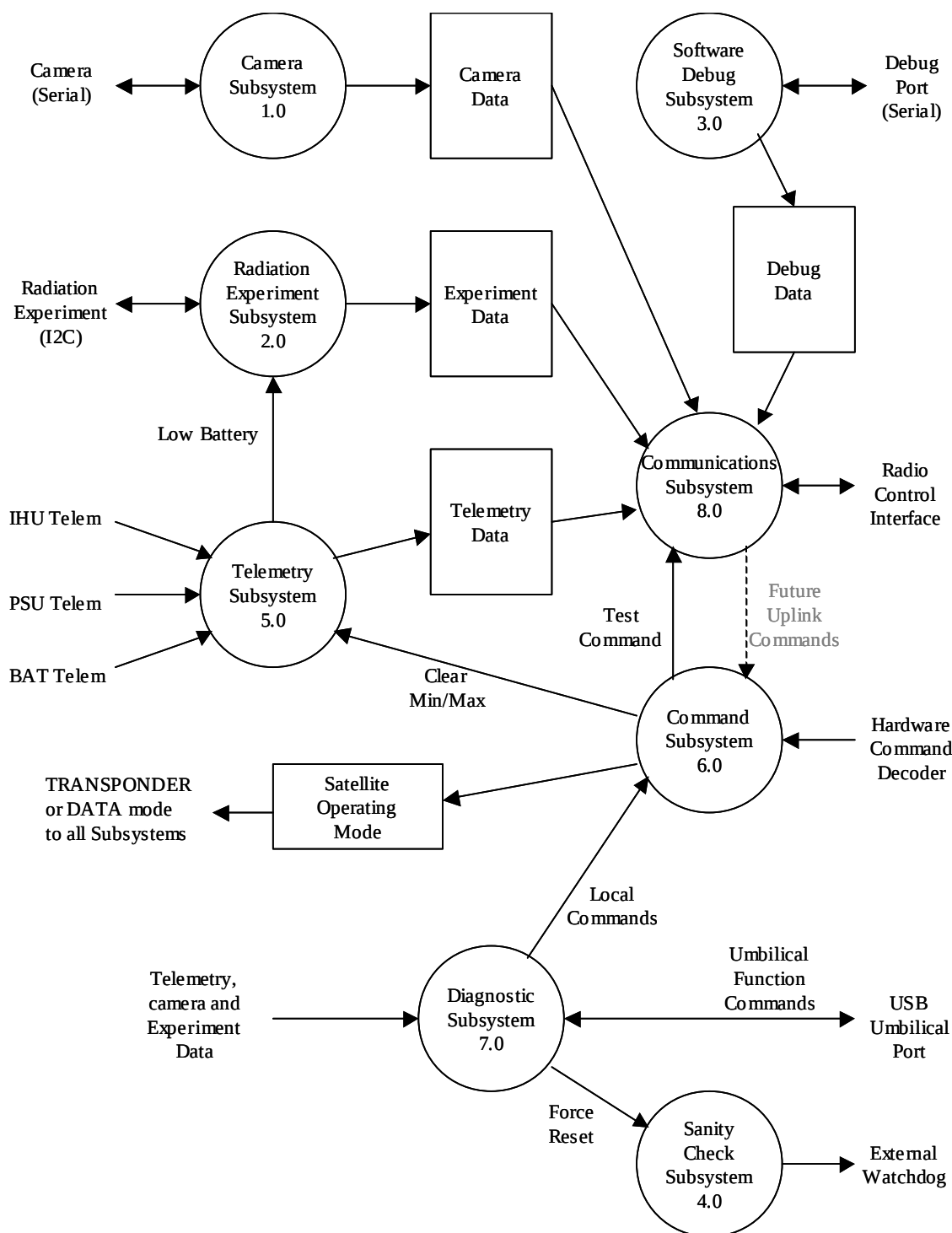
Run POST;
if (POST Failed) {
    halt and let external watchdog timer fire to try again
}

// POST passed
// See if we need to deploy the antennas
if (Umbilical Port is providing power) {
    break;          // do NOT deploy antennas!
}
else if (Both antennas are already deployed) {
    break;          // no need to deploy antennas
}
else if (One antenna is already deployed) {
    Deploy remaining antenna;
    break;
}
else {
    // Just released from P-POD
    // Antennas not deployed
    wait for 45 minutes;          // remember to pulse Watchdog
    Deploy RX antenna;
    Deploy TX antenna;
    break;
}

increment IHU Reset Count in MRAM;
set Command Mode to HIGH;
boot up system;
```

5 Application Software Data Flow Diagram

This shows the application software subsystems and their interfaces after the start up sequence has been executed (i.e. after system boot up.) The required functionality of each subsystem is specified in this section.



5.1 Camera Subsystem (1.0)

This subsystem runs the camera. The Camera is only used in DATA mode.

```
// Camera Processing
// Satellite in DATA mode

Turn ON power to Camera Card;
Initialize Camera parameters;

while (Satellite is in DATA mode) {
    Tell Camera to take a snapshot;

    while( Camera has data to send) {
        Get data from Camera;
        Store in Camera Data Buffer
    }
    Send Camera Data to Communications Subsystem;
}

// If Satellite switched to TRANSPONDER mode
Turn Camera card OFF;
Clear Camera Data Buffer;
Do nothing until satellite switches to DATA mode;
```

5.2 Radiation Experiment Subsystem (2.0)

This subsystem is responsible for running the experiment, collecting the experiment data , putting the experiment data into the Experiment Data Buffer and sending it to the Communications Subsystem. The experiment must be turned off and processing stopped if the Low Battery indication is received from the Telemetry subsystem.

5.3 Software Debug Subsystem (3.0)

There are no flight requirements for this subsystem. It is available for software development purposes and will be disabled for flight. There is a serial debug port that may be used for simple messages (printf.) There is also a debug data store available that will allow data to be transmitted along with the telemetry data on the downlink. This will allow non-flight parameters to be provided during software development.

5.4 Sanity Check Subsystem (4.0)

This subsystem verifies the integrity of the running software and pulses the Watchdog signal to reset the external watchdog timer. It will stop pulsing the Watchdog signal if it detects a fault or if it receives a command from the Diagnostic subsystem to force a reset.

5.5 Telemetry Subsystem (5.0)

This module is responsible for collecting all of the telemetry information from the interfaces, doing the Min/Max processing and providing the complete set of real-time, minimum and maximum telemetry parameters in the Telemetry Data Buffer. Note that this data is to be in the packed binary format as specified in the Telemetry Data section of the Downlink Protocol Specification.

5.5.1 Telemetry Subsystem Processing Specification

```
// Telemetry Processing  
Do this every 15 seconds;
```

```
Get all telemetry parameters;
```

```
// Check Battery  
If (Bus Voltage < 3.5 volts) {  
    Send LOW BATTERY indication to Radiation Experiment Subsystem;  
}
```

```
// Do MinMax processing  
Read Min/Max Data from MRAM memory;  
If (any errors) {  
    Increment MRAM memory error counter;  
    Re-write data to clear errors;  
}  
if (Clear Min/Max command was received) {  
    Write current telemetry values to Min/Max;  
    Clear MRAM memory error counter;  
}  
else {  
    // Normal Min/Max processing  
    Compare current values with stored Min/Max data;  
    Write any new Min/Max data to MRAM memory  
}
```

```
Send telemetry data to Communications Subsystem
```

5.6 Command Subsystem (6.0)

This subsystem is responsible for interpreting and executing commands to the satellite. The commands can come from ground control stations via the Hardware Command Decoder interface or from the Diagnostics subsystem via the umbilical port. In the future, the satellite will also accept commands from the communications subsystem via the uplink (not implemented for *Fox-1*.)

The Local Commands from the Diagnostics subsystem are:

1. Clear Telemetry Min/Max data
2. Got to Transponder Mode
3. Go to Data Mode
4. Send Test Message

The Command subsystem is responsible for setting the satellite operating mode. This is used by several subsystems to control their operation. If the satellite is commanded into DATA Mode, it must automatically switch back to TRANSPONDER mode after 24 hours unless a new DATA Mode command has been received.

5.6.1 Command Subsystem Processing Specification

// Command Processing

Set Satellite Operating Mode to TRANSPONDER; // This is the default at power-up

Do this continuously {

 Wait for a new command;

 switch(command) {

 case Clear Telemetry MinMax:

 Send Clear Min/Max message to Telemetry subsystem

 break;

 case Transponder Mode:

 Stop 24 Hour timer;

 Set Satellite Operating Mode to TRANSPONDER;

 break;

 case Data Mode:

 Start or re-start the 24 hour timer;

 Set Satellite Operating Mode to DATA;

 break;

 case Send Test Message:

 Send Test Command to Communications subsystem

 break;


```
default:
    // No processing for TX and IHU INHIBIT or ENABLE commands
    Do nothing;
}

if (24 hour timer expires) {
    Set Satellite Operating Mode to TRANSPONDER;
}
}
```

5.7 Diagnostic Subsystem (7.0)

This subsystem implements a local user interface on the satellite through the Umbilical USB port. This is expected to be used for system testing and launch integration activities. The Diagnostic Subsystem can read data from any Data buffer and can send commands to the Command and Idle subsystems. It is also available for software development use. This subsystem is not used in orbit. Note that if the satellite is being powered by the USB Umbilical port, the antennas **MUST NOT** be deployed and the Communications subsystem will prevent the transmitter power amp from being activated.

The following functions are the minimal set that is required. Additional commands can be added as needed.

5.7.1 Umbilical Port Get Functions

1. Get Telemetry Data
2. Get Experiment Data (n= 1-4)
3. Get Satellite Mode (command or transponder mode)
4. Get Satellite Up time (MET)
5. Get IHU Reset Count
6. Get Software Versions (IHU, PSU, BAT)

5.7.2 Umbilical Port Set Functions

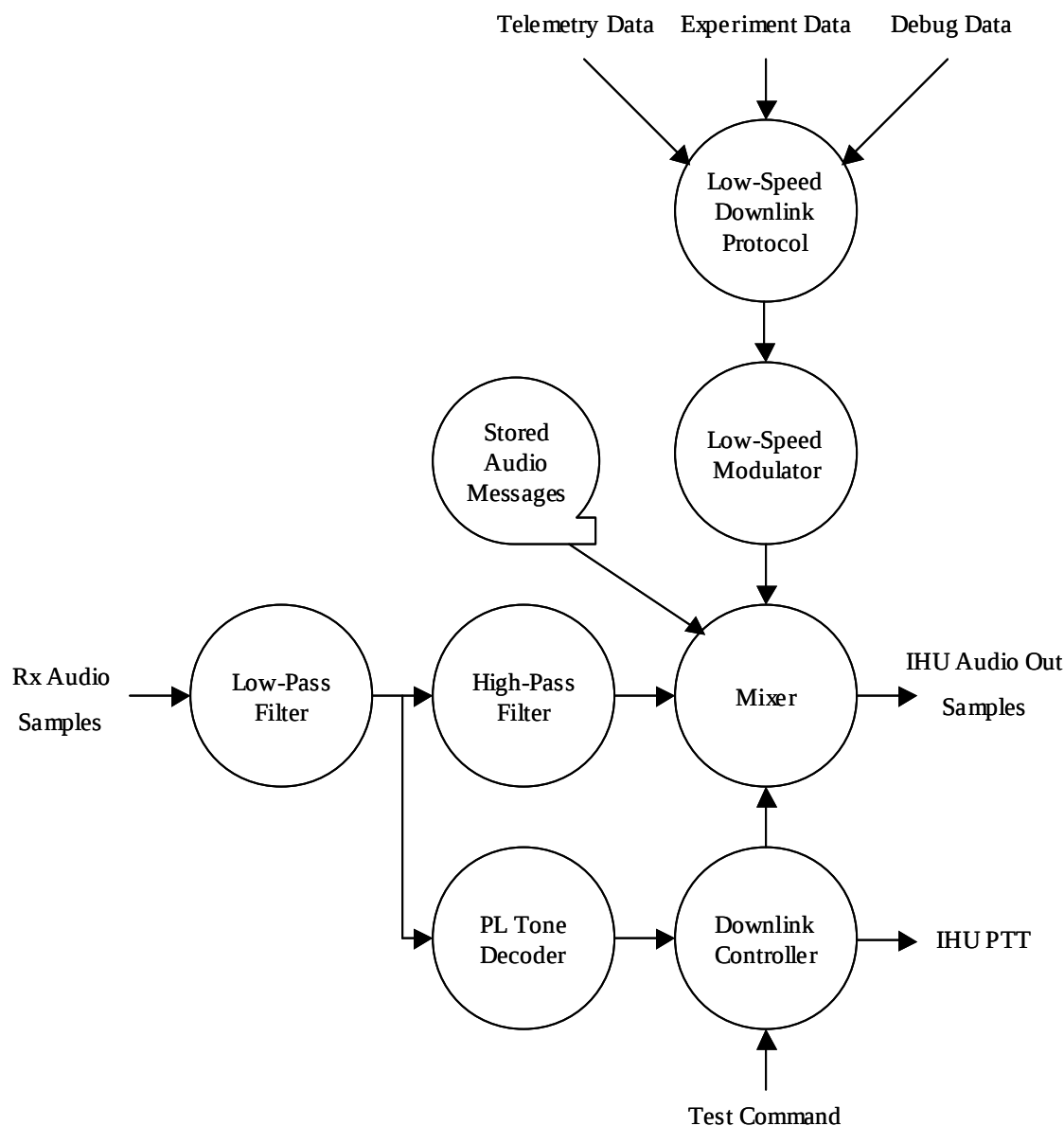
1. Load the CPU Program (FLASH) Memory
2. Clear Telemetry Min/Max data
3. Clear IHU Reset Count
4. Clear MRAM error count
5. Got to Transponder Mode
6. Go to Data Mode
7. Send Test Message
8. Reset CPU (let external watchdog timer fire)
9. Force Antenna Deployment (only if NOT powered by USB port)

5.8 Communications Subsystem (8.0)

This subsystem operates differently in TRANSPONDER and DATA modes.

5.8.1 Communications Subsystem TRANSPONDER Mode Operation

The diagram below shows the Communications subsystem data flow in TRANSPONDER mode.



The Low-Speed Downlink Protocol multiplexes the Telemetry, Experiment and Debug Data and adds the header and forward error correction (FEC) fields as specified in the Downlink Protocol Specification. The resulting bit-stream is fed to the Low Speed Modulator which creates the audio samples for transmission.

The Rx audio samples from the RF receiver are sent to a 3 kHz low-pass filter which feeds a 300 Hz high-pass filter and the PL Tone detector. The high-pass filter removes all of the audio components below 300 Hz so the spectrum is clean for the low-speed data downlink signal. The filtered audio signal is sent to the Mixer.

The Mixer can select and combine the low-speed data downlink signal and the filtered Rx audio signal or a Stored Audio Message under control of the Downlink Controller. The Stored Audio Messages include the Beacon message, Test message and Silence.

The PL Tone decoder detects the presence of a 67 Hz PL tone and sends an indication of this to the Downlink Controller.

5.8.1.1 Downlink Controller - TRANSPONDER mode Processing Specification

// Downlink Controller TRANSPONDER mode Processing

```
When satellite enters TRANSPONDER mode {
    Turn off IHU PTT;
    Set Mixer source to Rx Audio and Low-Speed Modulator;
}

do {
    if (PL Tone Detected) {
        if( NOT powered from USB port ) {
            Turn on IHU PTT;
        }
        Start or restart 2-minute Hang Timer;
        Stop Idle Timer;
    }

    if (Hang Timer Expires) {
        Turn off IHU PTT;
        Start 2 minute Idle Timer;
    }
}

// continued on next page
```

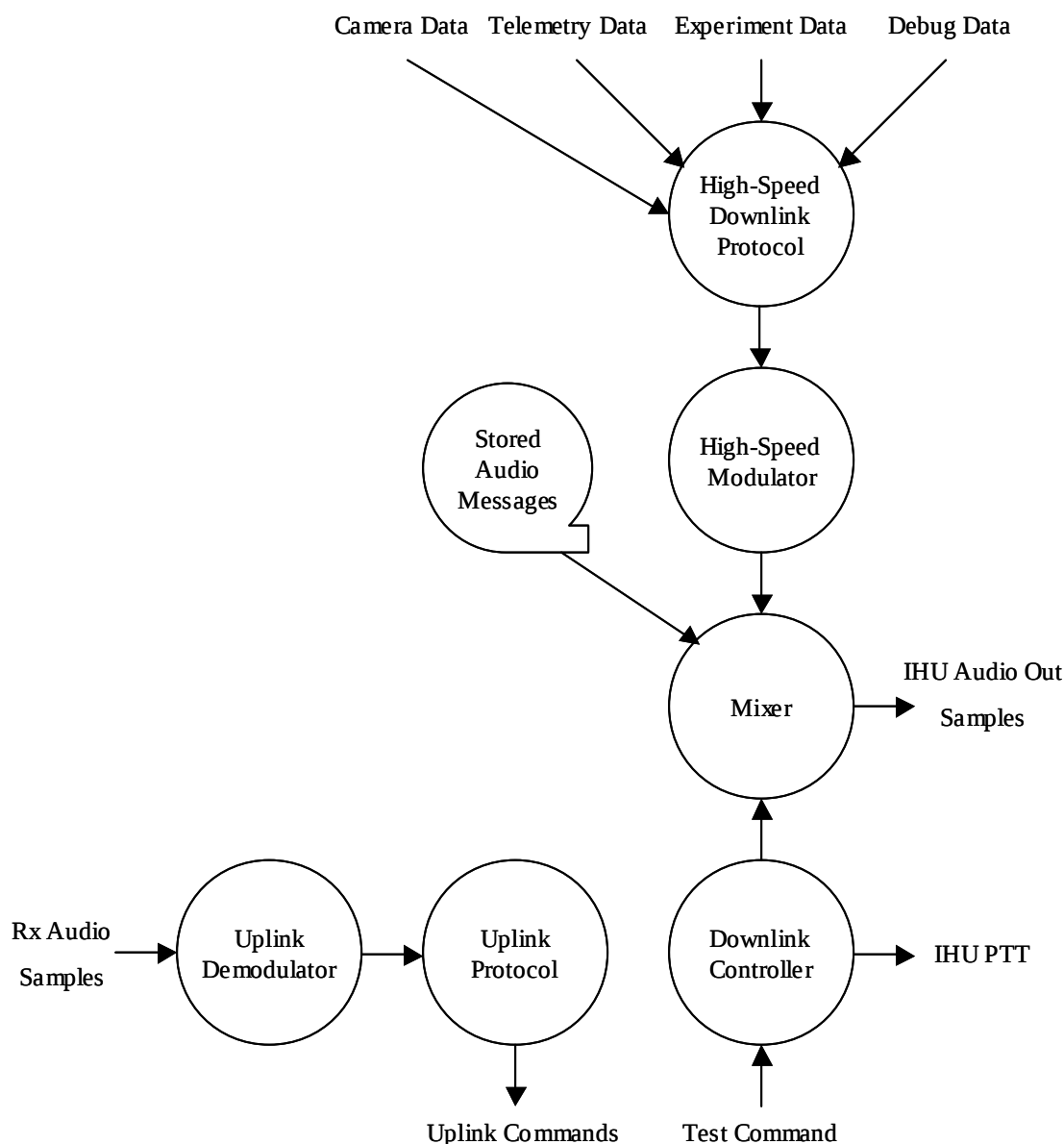
```
if (Idle Timer Expires) {
    Set Mixer source to Silence;
    if( NOT powered from USB port ) {
        Turn on IHU PTT;
    }
    Wait 5 seconds;      // For Douglas!
    Set Mixer source to Low-Speed Modulator and Beacon Message;
    Wait until Beacon Message sent;
    Set Mixer source to Low-Speed Modulator and Silence;
    Wait 6 seconds;
    Turn off IHU PTT;
    Set Mixer source to Rx Audio and Low-Speed Modulator;
    Re-start Idle Timer;
}

if (Test Command received) {
    if( NOT powered from USB port ) {
        Turn on IHU PTT;
    }
    Wait 1 second;
    Set Mixer source to Test Message and Low-Speed Modulator;
    Wait until Test Message sent;
    if (Hang Timer is not running) {
        Wait 1 seconds;
        Turn off IHU PTT;
    }
    Set Mixer source to Rx Audio and Low-Speed Modulator;
}

}
// end of TRANSPONDER mode, downlink controller processing
```

5.8.2 Communications Subsystem Data Mode Operation

The diagram below shows the Communications subsystem data flow in DATA mode.



The High-Speed Downlink Protocol multiplexes the Camera, Telemetry, Experiment and Debug Data and adds the header and forward error correction (FEC) fields to create downlink frames. The resulting bit-stream is fed to the High-Speed Modulator which creates the audio samples for transmission. The Mixer can select the Modulator samples or a selected Stored Audio Message under control of the Downlink Controller. The Stored Audio Messages include the Beacon message, Test message and silence. The uplink demodulation and protocol functions are not implemented in *Fox-1* but are shown for completeness.

5.8.2.1 Downlink Controller DATA mode Processing Specification

// Downlink Controller DATA mode Processing

```
When Satellite enters DATA mode {  
    Set Mixer Source to High-Speed Modulator only;  
    if( NOT powered by USB port ) {  
        Turn on IHU PTT;  
    }  
}  
  
do {  
    if (Test Command received) {  
        Set Mixer source to Silence;  
        Wait 1 second;  
        Set Mixer source to Test Message;  
        Wait until Test Message sent;  
        Set Mixer source to Silence;  
        Wait 1 second;  
    }  
    Set Mixer Source to High-Speed Modulator;  
}  
while (satellite is in DATA mode)  
  
// Satellite switched to TRANSPONDER mode  
Turn off IHU PTT;  
Do nothing until satellite goes back into DATA mode;
```

6 System Considerations

6.1 Operating System

The IHU software will use the free version of the FreeRTOS operating system.

6.2 Physical Device Drivers

These physical device drivers are needed to access and control the STM32 I/O interfaces.

1. I²C Bus
2. SPI Bus
3. UART
4. A/D converter channels
5. D/A converter channels
6. GPIO inputs
7. GPIO outputs

6.3 Performance Requirements

The Rx Audio A/D and the IHU Audio D/A converters have hard real-time requirements. DMA should be considered to offload the CPU for these interfaces.

6.4 Operational Constraints

The software is intended to run on orbit but must also be able to run inside the P-Pod to support the launch integration activities. Inside the P-POD, the power for the satellite will come from the USB Umbilical port. When powered from this port (i.e. inside the P-POD,) the antennas **MUST NOT** be deployed and the RF transmitter power amp **MUST NOT** be turned on.

6.5 Modularity and Maintainability

The experiments will be different for each future *Fox-1* type satellite mission. The experiment and camera processing software needs to be modularized so that they are easy to change.

7 Closing Notes

This document provides the desired behavior and a structure for the IHU software. It is expected that appropriate design documentation will be provided in addition to this document to describe the implementation details.

Introduction to Fox1 Mechanical Drawings

Robert Davis, KF4KSS

The following 54 pages are the current drawings for AMSAT's Fox1 cubesat. These are draft, and in a few circumstances, the design has been modified slightly from the drawings as currently updated. Some drawings use color, if meaningful information can be shared, like material or circuit board layout. All drawings should be considered draft, as we have not committed to fabrication of flight units yet. However, in many instances, the drawings represent a very mature design.

We are just about to assemble engineering units, which would be available for operational testing, mechanical fit checks, and prototype environmental tests. For some parts, earlier prototypes were also built. This year, prototypes were built that have helped mature the design of the PCB Stack, sheetmetal Walls, and Solar Panel printed circuit boards. We now have many pieces on hand, and we're looking out for things like assembled tolerances. Significant prototype effort has also been placed in the +Y and -Y Solar Panels, which share a common circuit board design but populated differently for the RX and TX antennas. Long-term stow, vibration resistance, and deploy tests will be starting soon on those antennas. A thermal vacuum test of the battery board is also imminent.

Our progress has only been possible through the efforts of multiple people, within our small mechanical team and across many disciples and components.

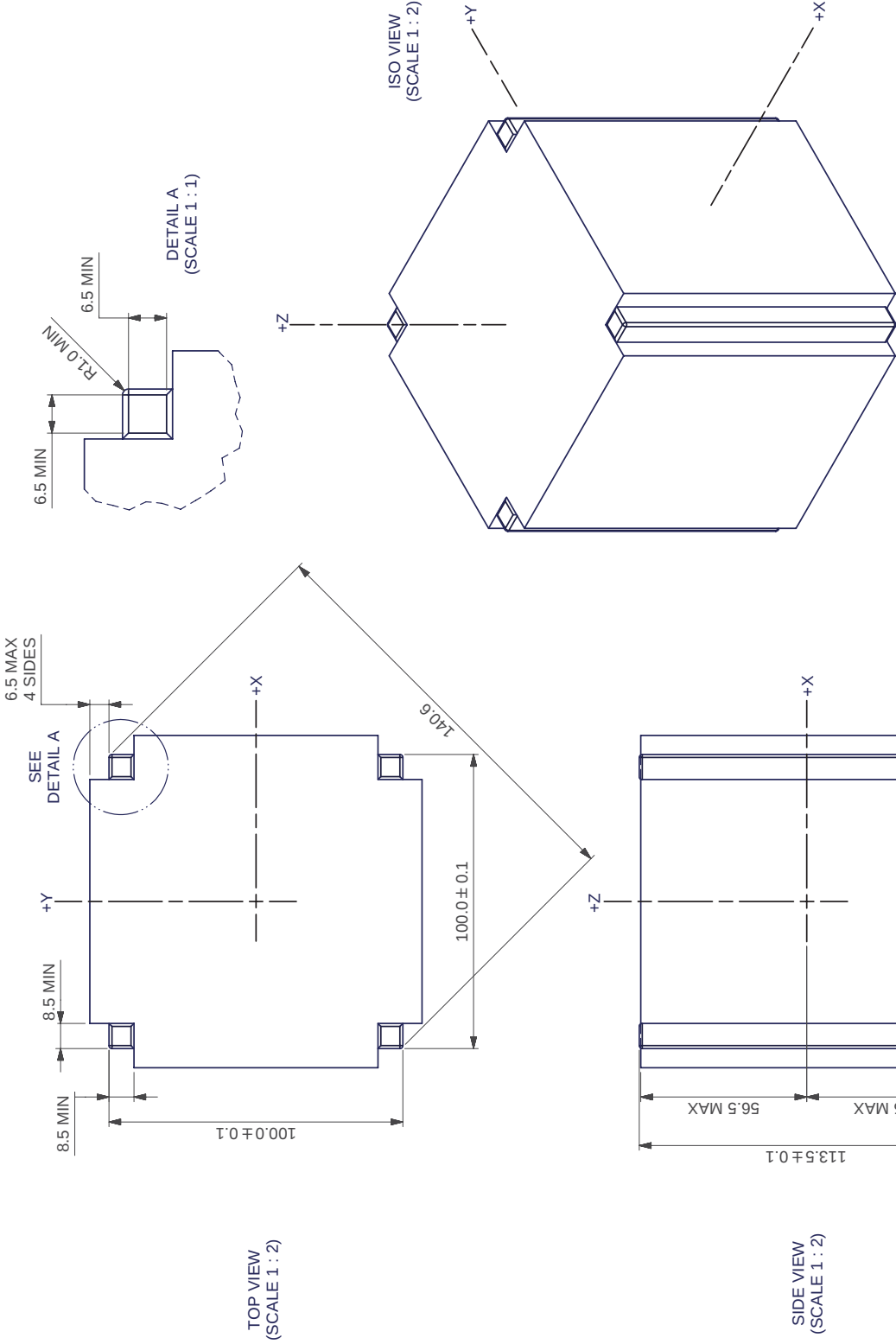
Please consider volunteering!



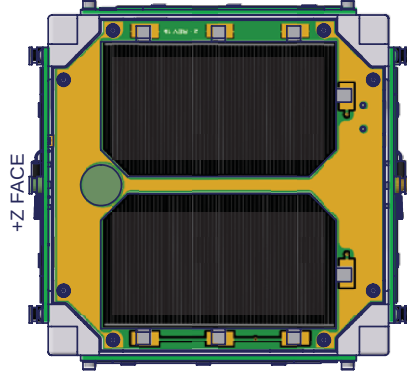
AMSAT
FOX

1U ENVELOPE

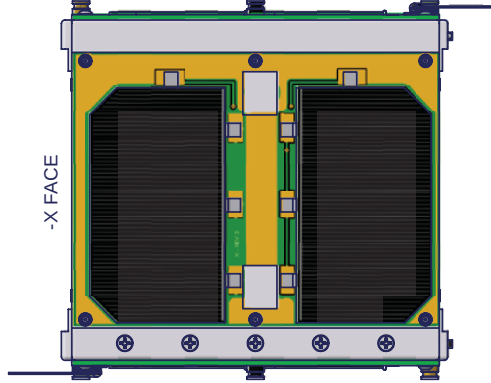
SIZE	DATE	DWG NO	REV
A	2011-04-04	FOX-ME-101	0.2
SCALE	1 : 2	UNLESS NOTED OTHERWISE:	SHEET 1/1



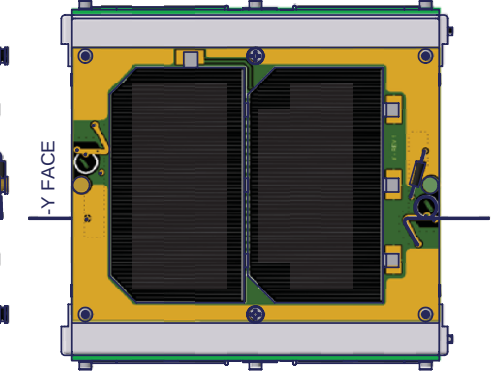
- NOTES:
- 1) INTERPRETATION OF CUBESAT DESIGN SPECIFICATION REV 12.
 - 2) ENVELOPE FOR ALL HARDWARE EXCEPT FREE STATE OF
A) PLUNGER OF TWO SEPARATION SPRINGS
B) PLUNGER OF ONE OR TWO CONTACT SWITCH(ES)
- SPRINGS AND SWITCH(ES)
ON RAILS OF -Z FACE;
SEE NOTE 2.



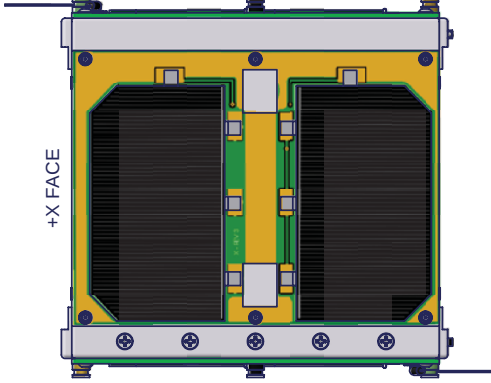
+Z FACE



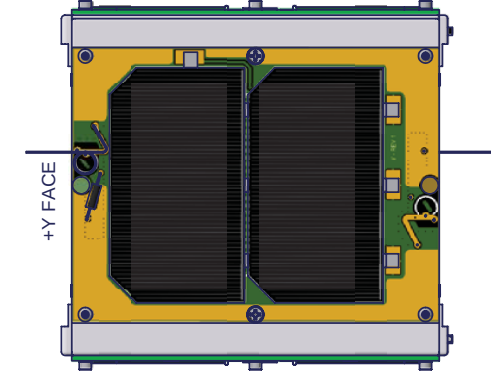
-X FACE



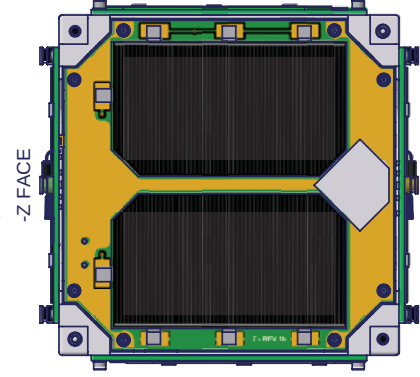
-Y FACE



+X FACE



+Y FACE



-Z FACE

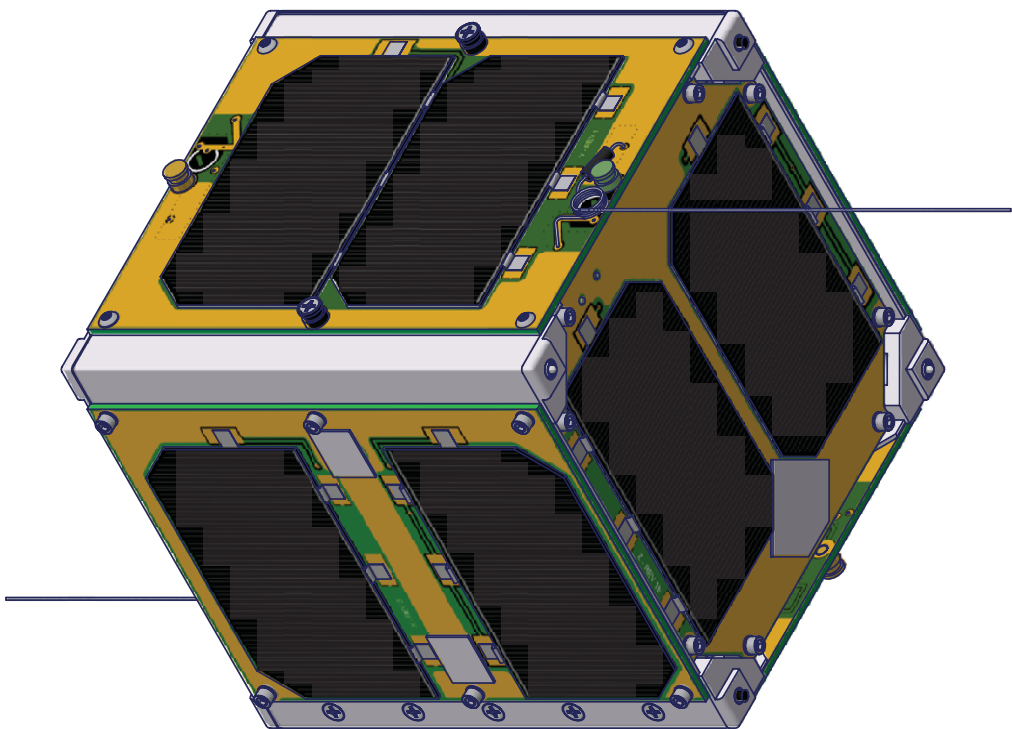
DEPLOYED
(ANTENNAS CROPPED)
SCALE 1 : 2



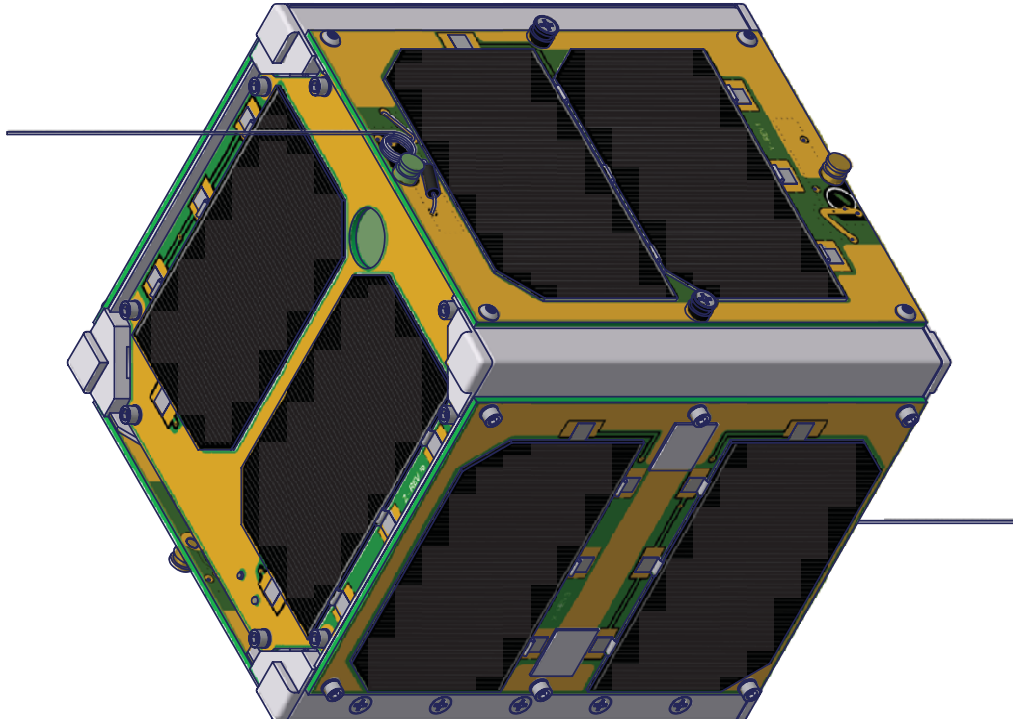
FOX1 ASSEMBLY

SIZE	DATE	DWG. NO.	REV.
A	2013-10-09	FOX-ME-103	0.4
SCALE	1 : 2	UNLESS NOTED OTHERWISE:	SHEET
		mm [in] TOL. X.X ± 0.2 X.XX ± 0.1	1 OF 5

ISO -X-Y-Z
SCALE 3 : 4



ISO +X+Y+Z
SCALE 3 : 4

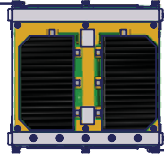


AMSAT FOX

FOX1 ASSEMBLY

SIZE	DATE	DWG. NO.	REV.
A	2013-10-09	FOX-ME-103	0.4
UNLESS NOTED OTHERWISE:			SHEET
SCALE	3 : 4	mm [in]	TOL. X.X ± 0.2 X.XX ± 0.1
			2 OF 5

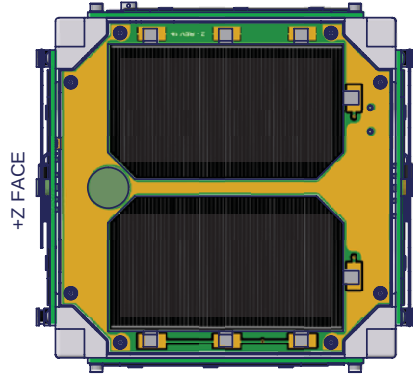
+X FACE
TRUE ANTENNA LENGTHS
SCALE 0.2 : 1



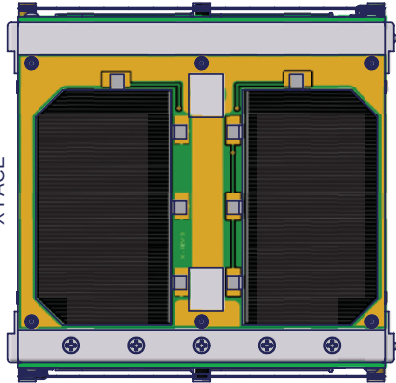
AMSAT FOX

FOX1 ASSEMBLY

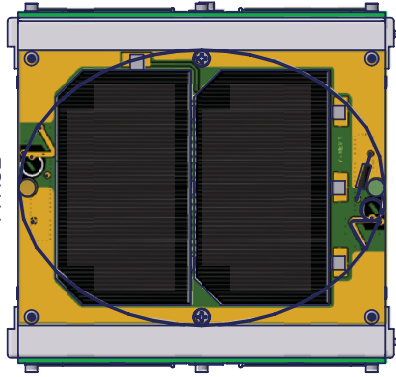
SIZE	DATE	DWG. NO.	REV.
A	2013-10-09	FOX-ME-103	0.4
SCALE			SHEET
1 : 5			3 OF 5
UNLESS NOTED OTHERWISE: mm [in] TOL. XX ± 0.2 XXX ± 0.1			



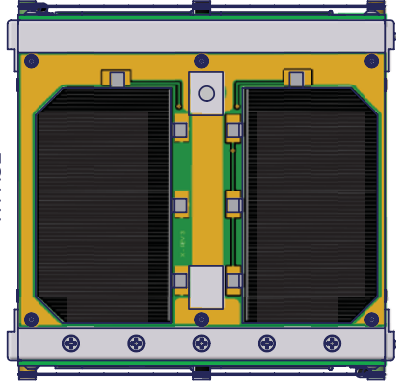
+Z FACE



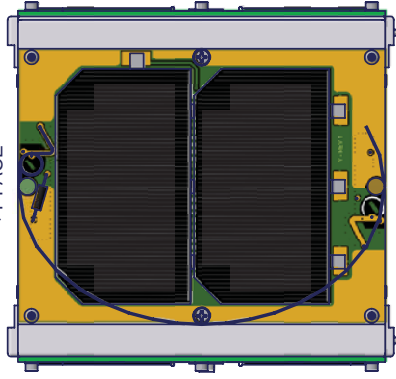
-X FACE



-Y FACE



+X FACE



+Y FACE

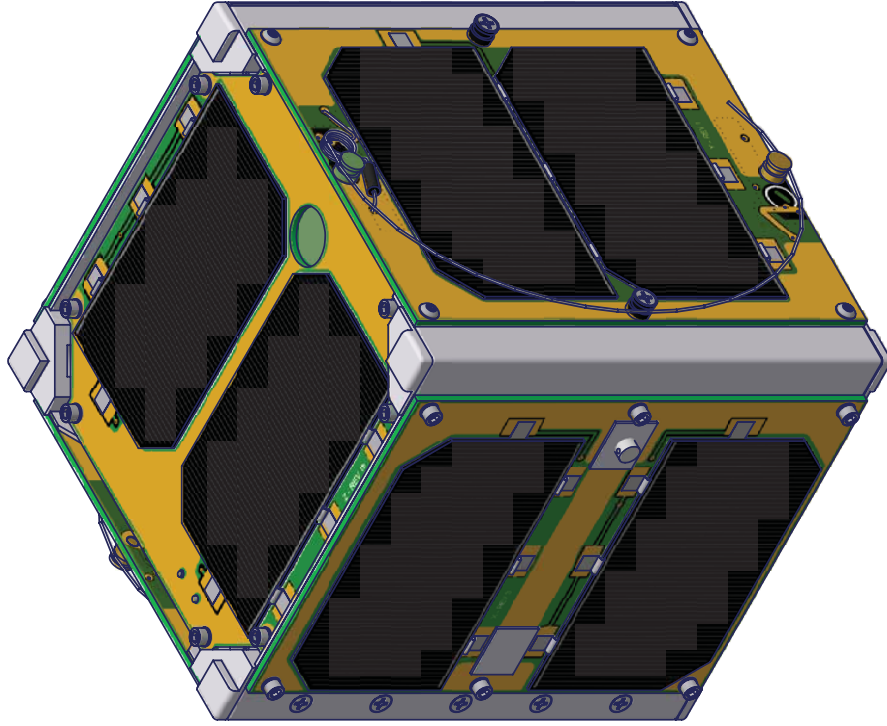
DEPLOYED
SCALE 1:2

AMSAT FOX

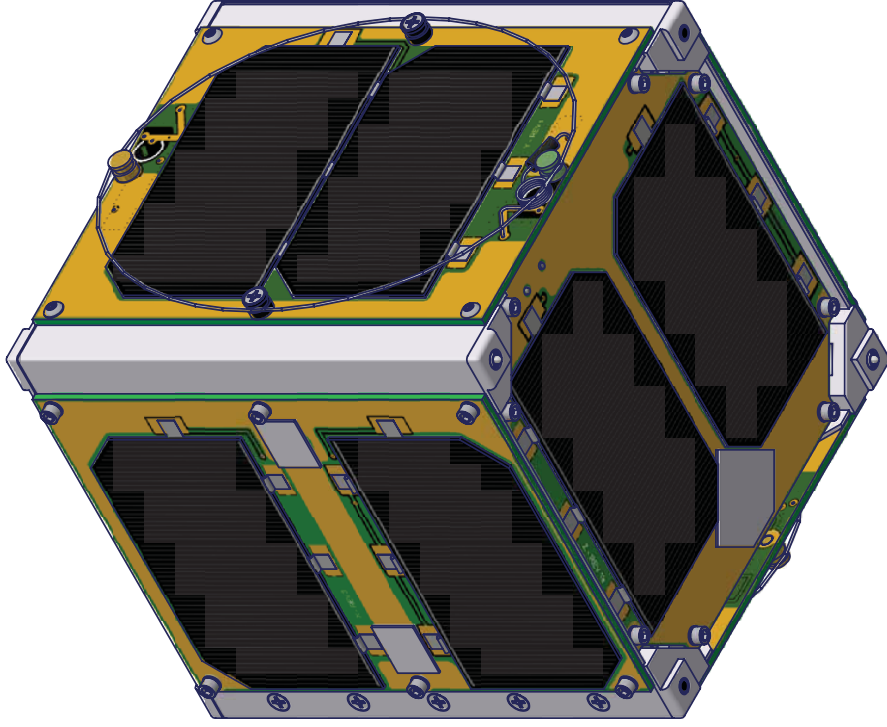
FOX1 ASSEMBLY

SIZE	DATE	DWG. NO.	REV.
A	2013-10-09	FOX-ME-103	0.4
UNLESS NOTED OTHERWISE:			SHEET
SCALE	1:2	mm [in]	TOL. X.X ± 0.2 X.XX ± 0.1

ISO +X+Y+Z
SCALE 3 : 4



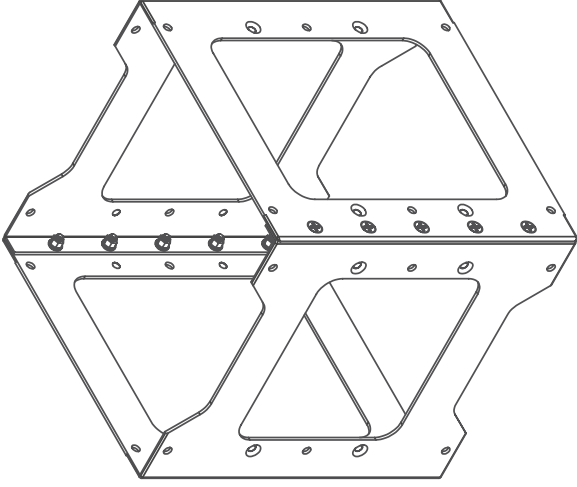
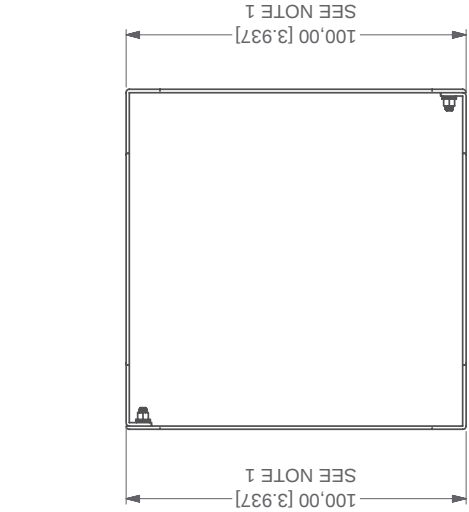
ISO -X-Y-Z
SCALE 3 : 4



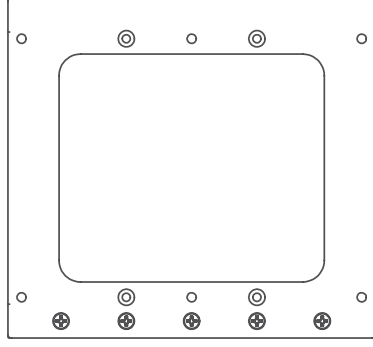
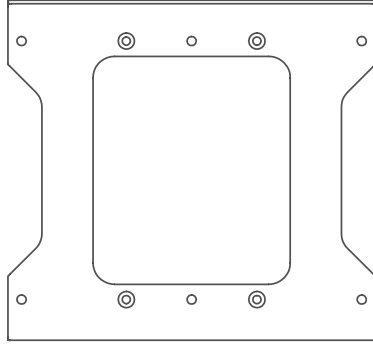
AMSAT FOX

FOX1 ASSEMBLY

SIZE	DATE	DWG. NO.	REV.
A	2013-10-09	FOX-ME-103	0.4
UNLESS NOTED OTHERWISE:			SHEET
SCALE	3 : 4	mm [in] TOL. X.X ± 0.2 X.XX ± 0.1	5 OF 5



-01 WALLS



- NOTES:
- 1) AT ASSEMBLY, ALIGN BOTH DIMENSIONS.
TORQUE #2-56 NUTS TO 2.5 IN-LB, OR 40 IN-OZ.
 2. CONFORMAL COAT OR EPOXY COAT
CAD-PLATED STEEL NUTS.

ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	FOX-ME-111-03	WALLS, BENT
3	10	MS21042-02	LOCK NUT, #2-56
4	10	NAS662C2R4 / MCMASTER-CARR 93085A017	FHCS, #2-56 X 1/4" X 100° SS
5	10	90945A705	WASHER, #2 THIN, NAS620C2
Parts List			

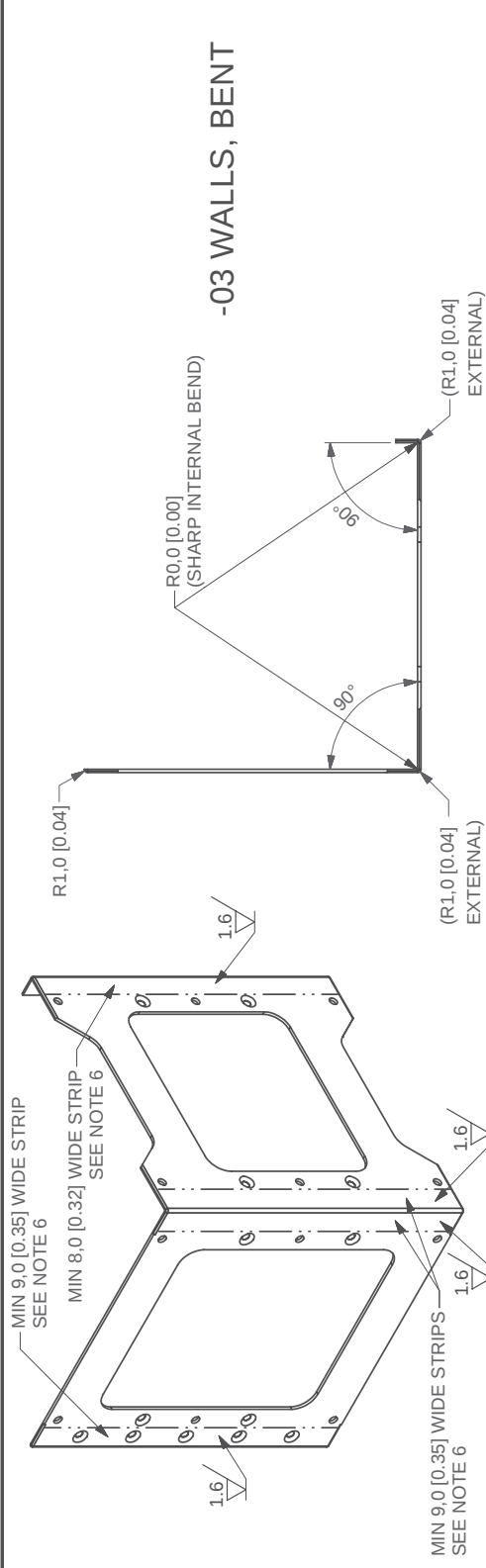


AMSAT
FOX

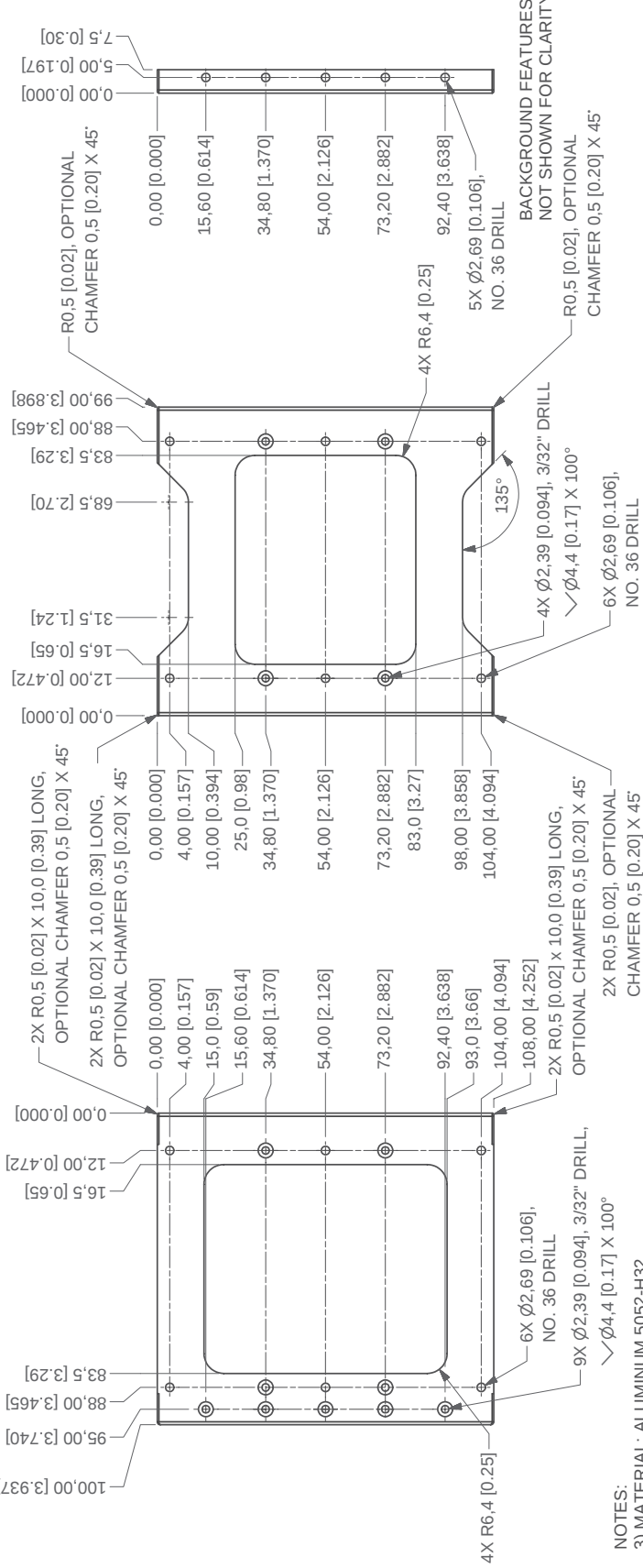
WALLS

SIZE A	DATE 2013-04-25	DWG. NO. FOX-ME-111	REV. 0.6
SCALE 1 : 2			SHEET 1 OF 3

UNLESS NOTED OTHERWISE:
mm [in] TOL. X.X ± 0.2 X.XX ± 0.1

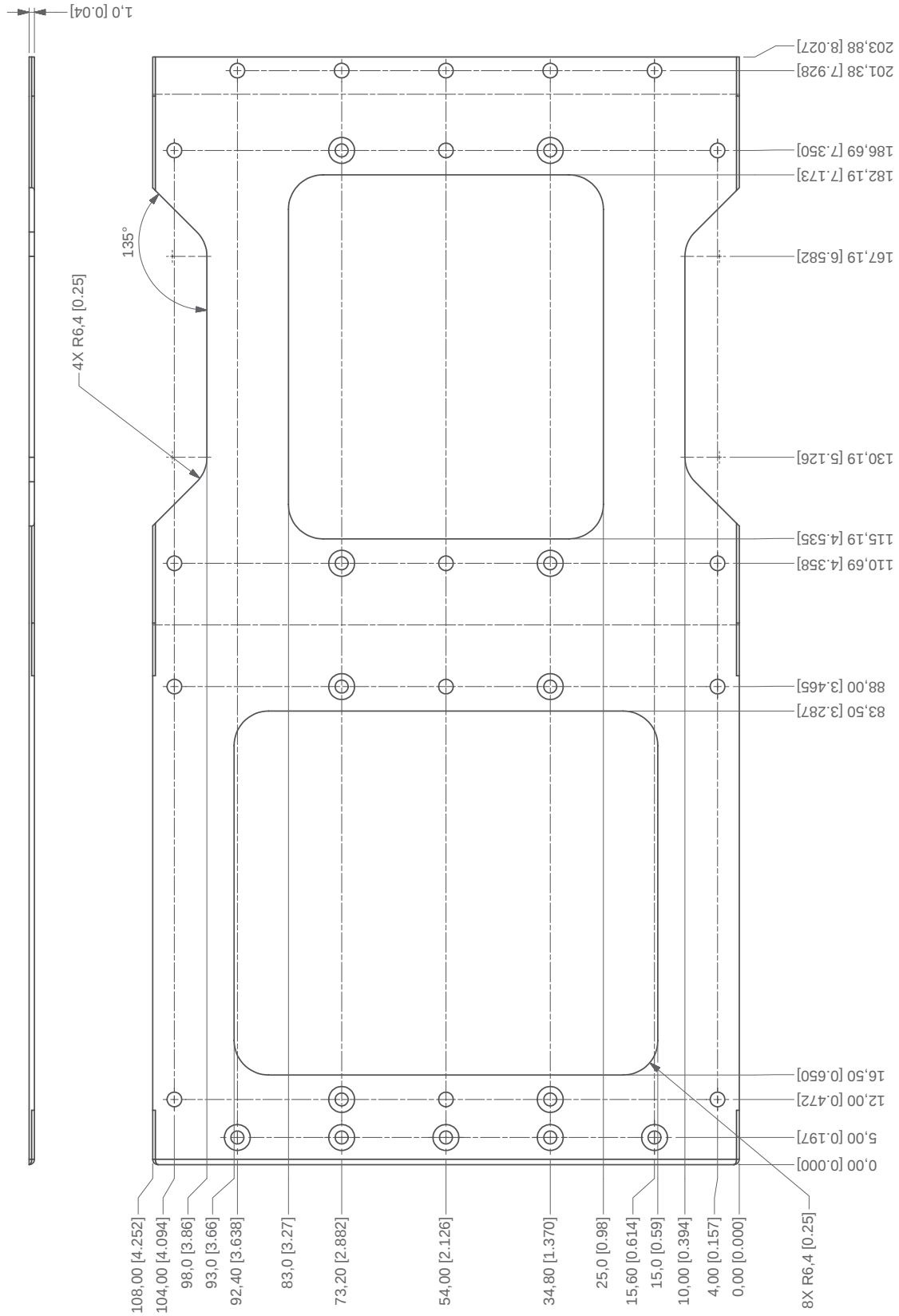


-03 WALLS, BENT



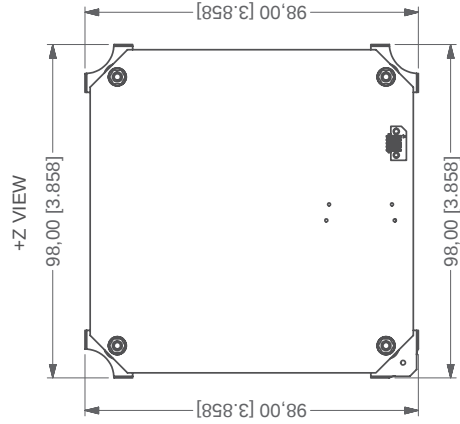
- NOTES:
- 3) MATERIAL: ALUMINUM 5052-H32.
 - 4) DO NOT SCUFF.
 - 5) CHEMICAL CONVERSION COAT PER MIL-DTL-5541 CLASS 3. ELECTRICALLY CONDUCTIVE CLEAR.
 - 6) HARD ANODIZE AREAS SHOWN PER MIL-A-8625 TYPE III, CLASS 1, CLEAR. INCLUDE BEND/ROUND, CONSUMED HOLES AND SHEETMETAL EDGES.

WALLS			
SIZE	DATE	DWG. NO.	REV.
A	2013-04-25	FOX-ME-111	0.6
SCALE		SHEET	
1 : 2		2 OF 3	

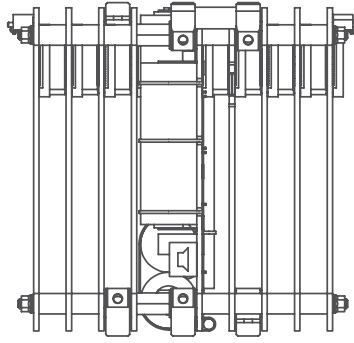


-03 WALLS, FLAT PATTERN
REFERENCE DIMENSIONS
POSITION/TOLERANCE FROM BENDS

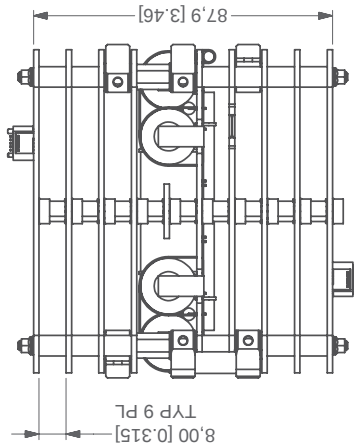
WALLS			
SIZE	DATE	DWG. NO.	REV.
A	2013-04-25	FOX-ME-111	0.6
SCALE		SHEET	
1 : 2		3 OF 3	
UNLESS NOTED OTHERWISE: mm [in], TOL. XX.XX ± 0.1			



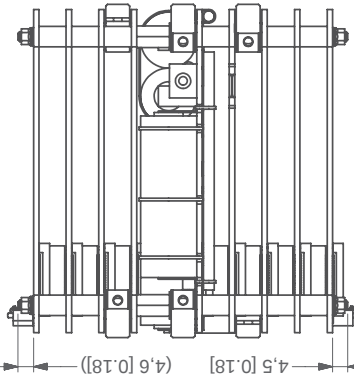
-Y VIEW



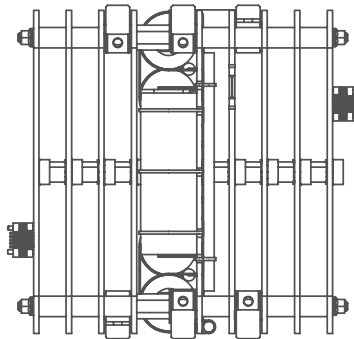
-X VIEW



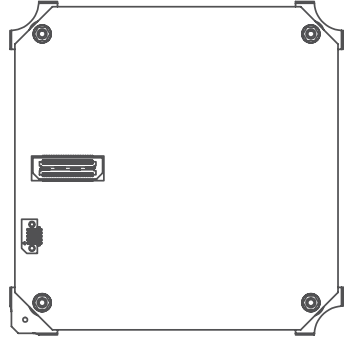
+Y VIEW



+X VIEW



-Z VIEW



PCB ASSEMBLY

SIZE	DATE	DWG. NO.	REV.
A	2012-08-15	FOX-ME-112	0.3
SCALE	1 : 2	UNLESS NOTED OTHERWISE:	SHEET
		mm [in] TOL. X.X ± 0.2 X.XX ± 0.1	1 OF 3

- 1) LOCATE ITEM 12 ON ITEM 11 TO PROTRUDE 4.5 [0.18]" FROM PCB.
- 2) STACK PCBs ITEMS 1-5 AS SHOWN USING SPACERS ITEMS 14-16.
CORNER -X-Y RECEIVES MAGNET BETWEEN 2X DELRIN ITEM 19.
CORNERS -X+Y, +X+Y, +X-Y RECEIVES 2X DELRIN ITEM 17.
VERTICAL SPACING BETWEEN DELRIN MOUNT SCREWS MAY BE ADJUSTED
BY MOVING SHIM WASHERS, ITEM 18.
- 3) TORQUE ITEM 16 TO TBD IN-LB.
- 4) ITEM 6 MAY BE PLACED BUT HAS NO HARDWARE.

20	1	FOX-ME-124		MAGNET
19	2	FOX-ME-118-03		PCB DELRIN MOUNT
18	32	MCMaster 90792A312		SHIM WASHER, 3/16" ID X 0.010"
17	6	FOX-ME-118-01		PCB DELRIN MOUNT
16	4	FOX-ME-117-05		AL THREADED SPACER
15	8	FOX-ME-117-03		CU SPACER FOR DELRIN
14	24	FOX-ME-117-01		AL SPACER
13	8	NAS620-C4L /		WASHER, #4 THIN
		MCMaster-CARR 90945A710		
12	8	MS21042-04		LOCKING NUT, #4-40
11	4	FOX-ME-123		THREADED ROD
10	1	FOX-ME-113-10		EXPERIMENT #4 PCB
9	1	FOX-ME-113-09		EXPERIMENT #3 PCB
8	1	FOX-ME-113-08		EXPERIMENT #2 PCB
7	1	FOX-ME-113-07		EXPERIMENT #1 PCB
6	1	FOX-ME-113-06		BATTERY #2 PCB
5	1	FOX-ME-113-05		BATTERY #1
4	1	FOX-ME-113-04		PSU PCB
3	1	FOX-ME-113-03		IHU PCB
2	1	FOX-ME-113-02		RX PCB
1	1	FOX-ME-113-01		TX PCB
ITEM	QTY	PART NUMBER		DESCRIPTION



5) STACK PCBs ITEMS 7-10 AS SHOWN USING SPACERS ITEMS 14-16. SPACING BETWEEN DELRIN MOUNT SCREWS MAY BE ADJUSTED BY MOVING SHIM WASHERS, ITEM 18.

6) TORQUE ITEM 16 TO TBD IN-LB.

PCB ASSEMBLY			
SIZE	DATE	DWG. NO.	REV.
A	2012-08-15	FOX-ME-112	0.3
SCALE	1 : 1		SHEET
		UNLESS NOTED OTHERWISE: mm [in]: TOX. XX ± 0.2 XXX ± 0.1	
			3 OF 3

+Z TOP VIEW (1 : 1)

+Y AXIS

4X $\phi 6.35$ [0.250]
PAD TO GROUND.
+Z TOP AND -Z BOTTOM SIDES.

4X $\phi 3.18$ [0.125]

95.00 [3.740]

87.00 [3.425]

85.00 [3.346]

84.00 [3.307]

80.50 [3.169]

4X COMPONENT STAY-OUT ZONES.
+Z TOP AND -Z BOTTOM SIDES.
PROVIDES 2.00 [0.079] CLEARANCE
BETWEEN COMPONENTS

+X AXIS

25.57 [1.007]
24.75 [0.974]

14.50 [0.571]

11.00 [0.433]

10.00 [0.394]

8.00 [0.315]

0.00 [0.000]

0.00 [0.000]

8.00 [0.315]

10.00 [0.394]

11.00 [0.433]

14.50 [0.571]

44.83 [1.765]

49.53 [1.950]

80.50 [3.169]

84.00 [3.307]

85.00 [3.346]

87.00 [3.425]

95.00 [3.740]

2X $\phi 1.02$ [0.040] #60 DRILL
ALIGNMENT HOLES FOR
SAMTEC QSH-030-01-L-D-A
ON -Z BOTTOM SIDE.

2X $\phi 1.02$ [0.040] #60 DRILL
ALIGNMENT HOLES FOR
SAMTEC QTH-030-02-L-D-A
ON +Z TOP SIDE.

1.59 [0.063]

TYPICAL PCB
SEE CONTINUATION SHEETS FOR
SPECIFIC PCB ADDITIONS / EXCEPTIONS.



AMSAT

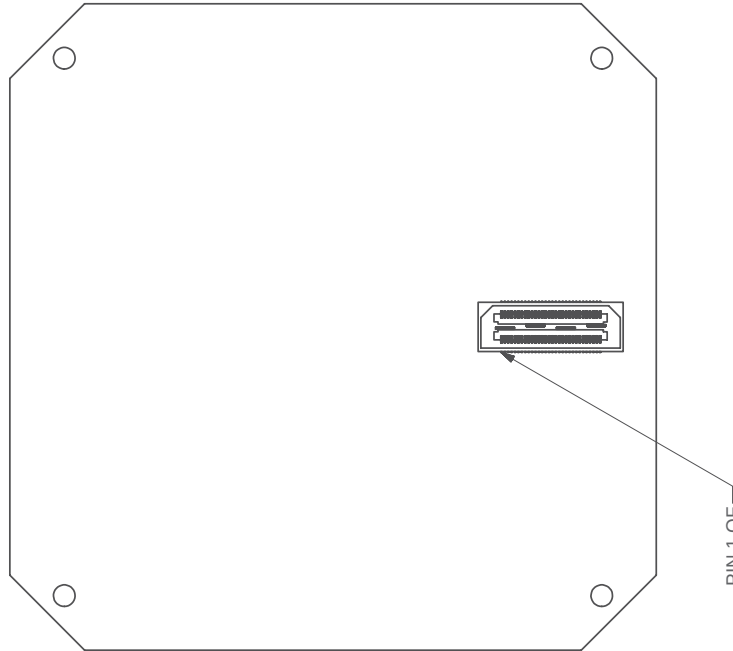
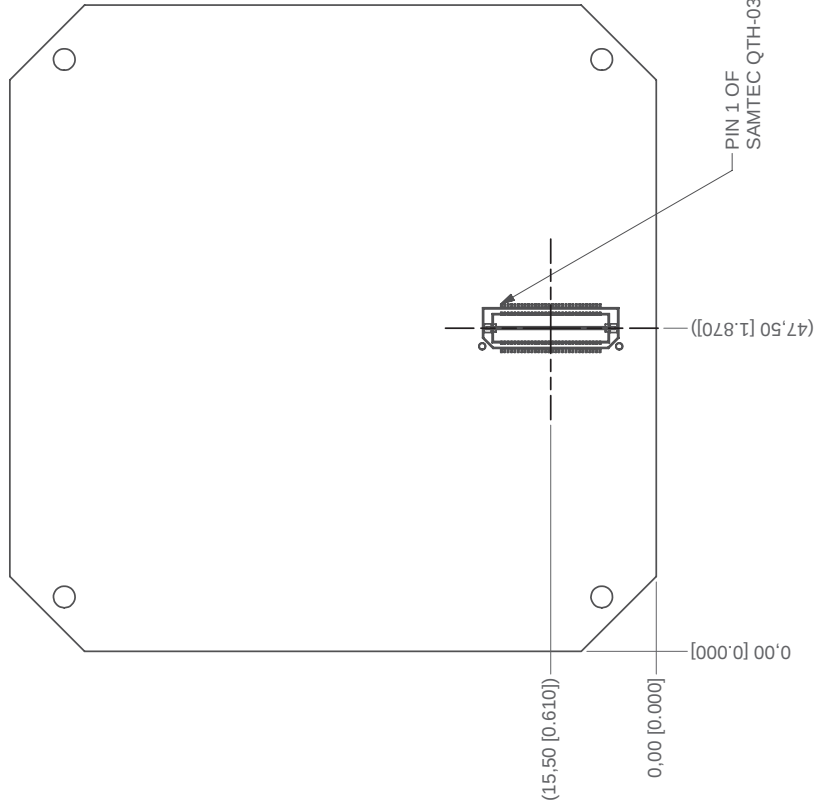
FOX

PCB

DATE	DWG. NO.	REV.
2013-07-19	FOX-ME-113	0.8
SHEET		
SCALE	1 : 1	UNLESS NOTED OTHERWISE: mm [in] TOL. X.X ± 0.2 X.XX ± 0.1

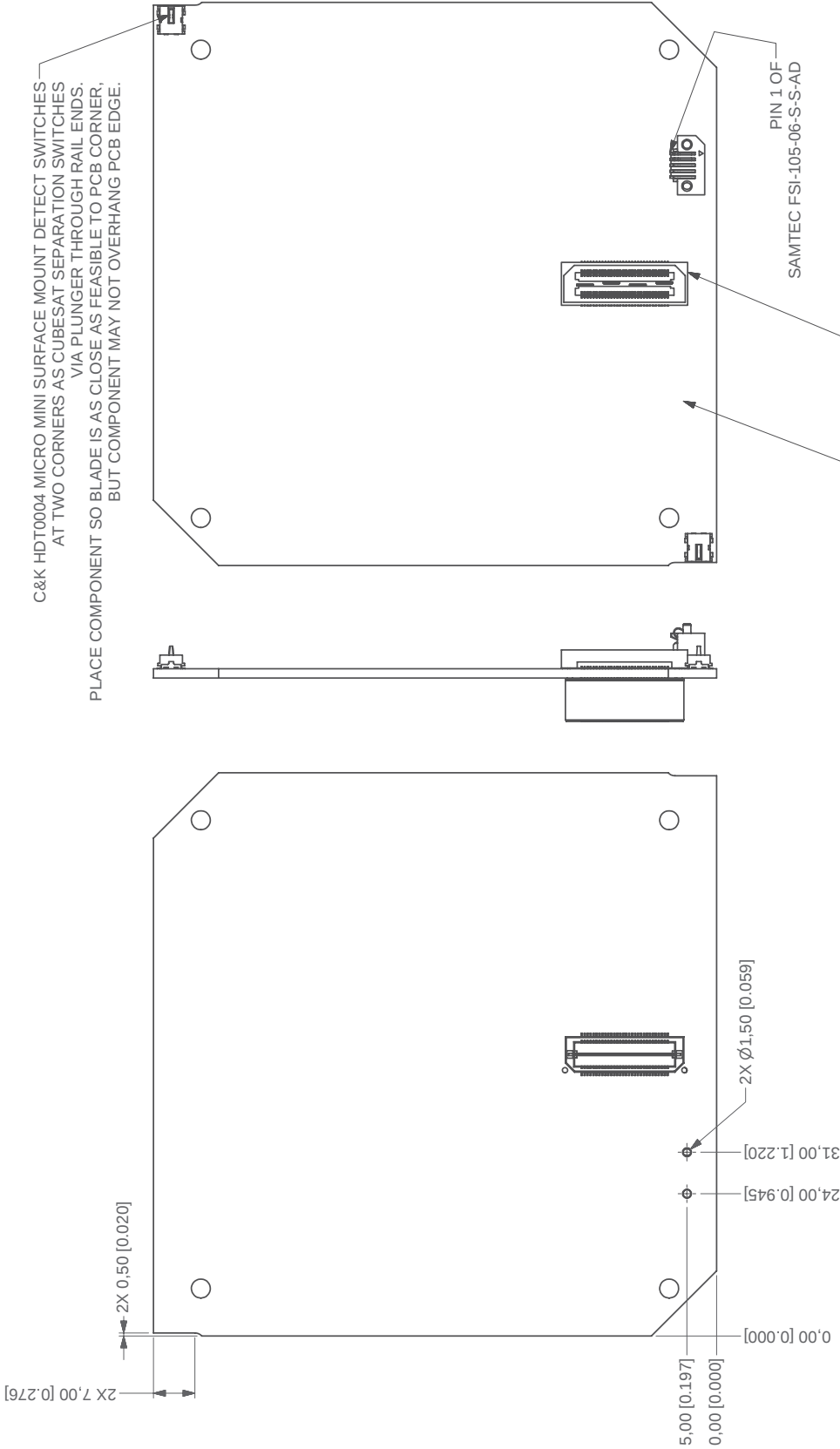
1 OF 11

+Z TOP VIEW



TYPICAL CONNECTORS
SEE CONTINUATION SHEETS FOR
SPECIFIC PCB ADDITIONS / EXCEPTIONS.

PCB			
SIZE	DATE	DWG. NO.	REV.
A	2013-07-19	FOX-ME-113	0.8
SCALE	1 : 1	UNLESS NOTED OTHERWISE: mm [in], TOL. XX.X ± 0.2 XX.XX ± 0.1	
		SHEET 2 OF 11	

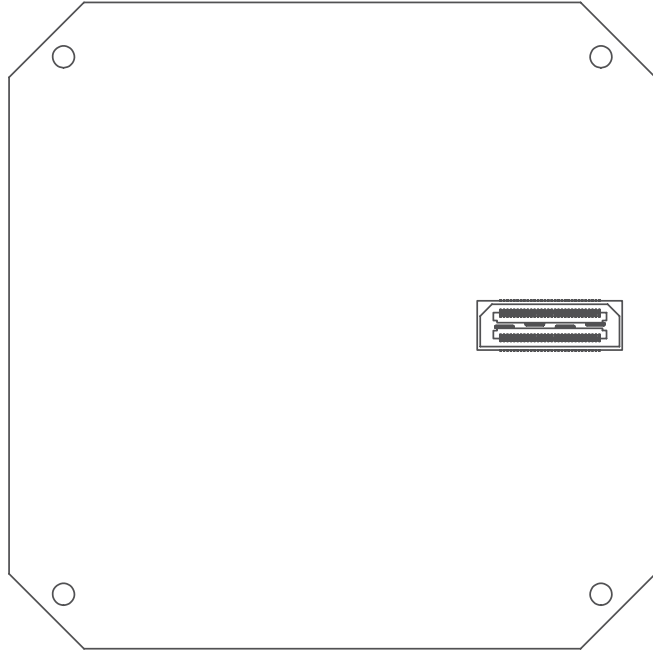
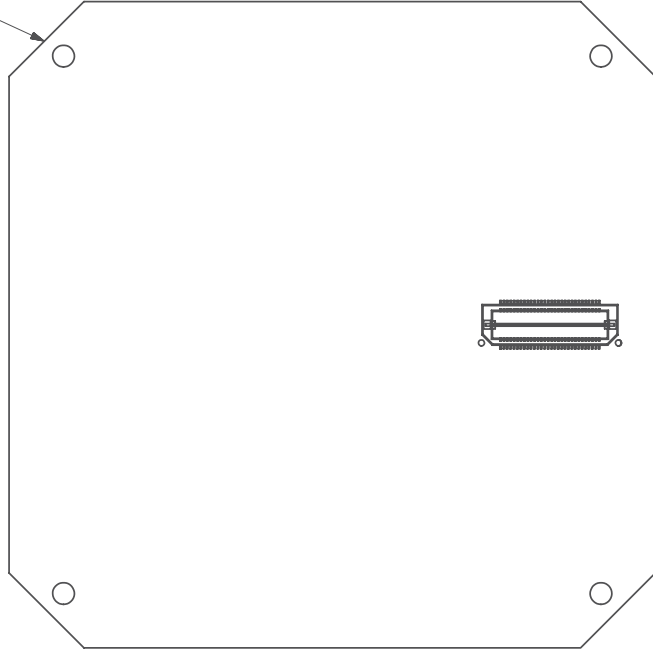


-01 TX

NOT USED IN FLIGHT.
MAY BE POPULATED FOR TEST UNITS.
FITS IN GAP TO -Z SOLAR PANEL.

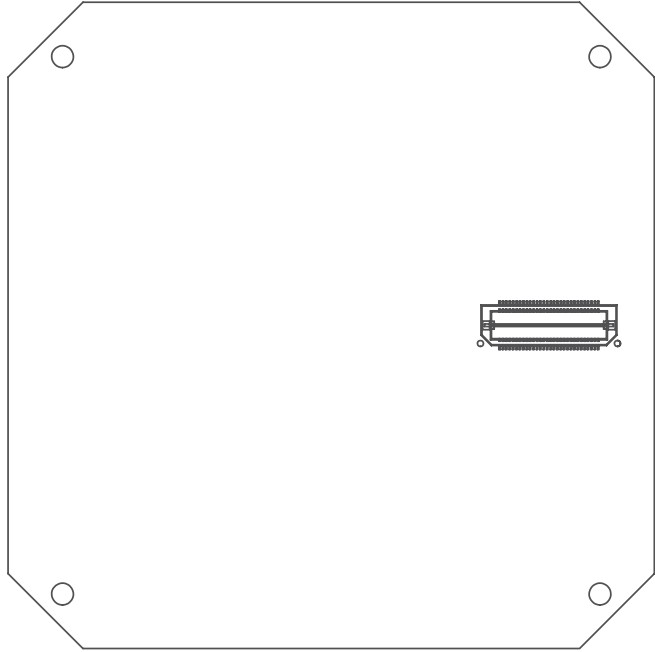
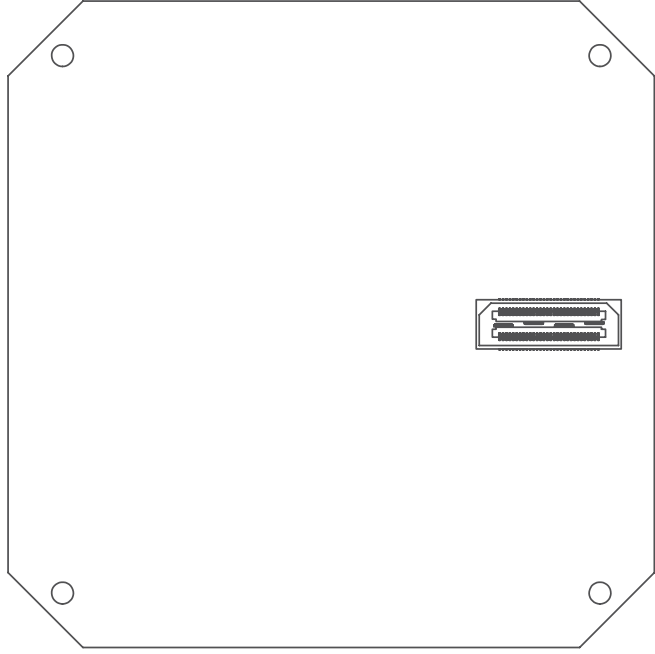
PCB			
SIZE	DATE	DWG NO.	REV.
A	2013-07-19	FOX-ME-113	0.8
SCALE		SHEET	
1 : 1		3 OF 11	
UNLESS NOTED OTHERWISE: mm [in] TOL. XX.XX ± 0.1			

COAX OVER THIS EDGE
TO -Y SOLAR PANEL



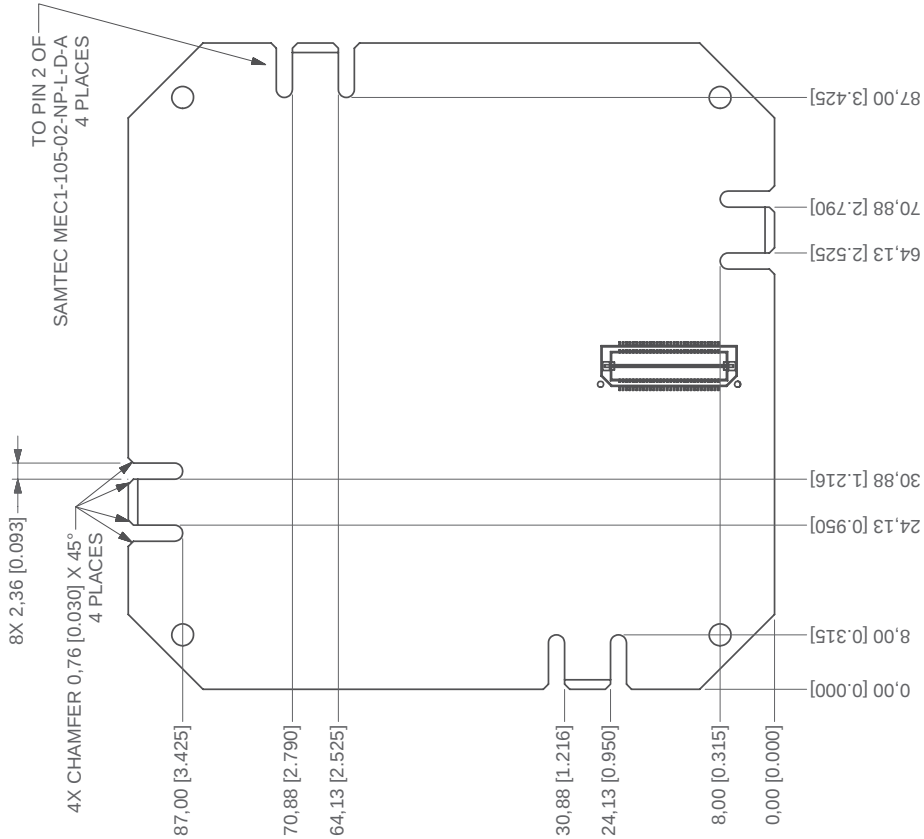
-02 RX

PCB				
SIZE	DATE	DWG. NO.	REV.	
A	2013-07-19	FOX-ME-113	0.8	
SCALE	UNLESS NOTED OTHERWISE:			SHEET
1 : 1	mm [in] TOL. XX ± 0.2 XX ± 0.1			4 OF 11

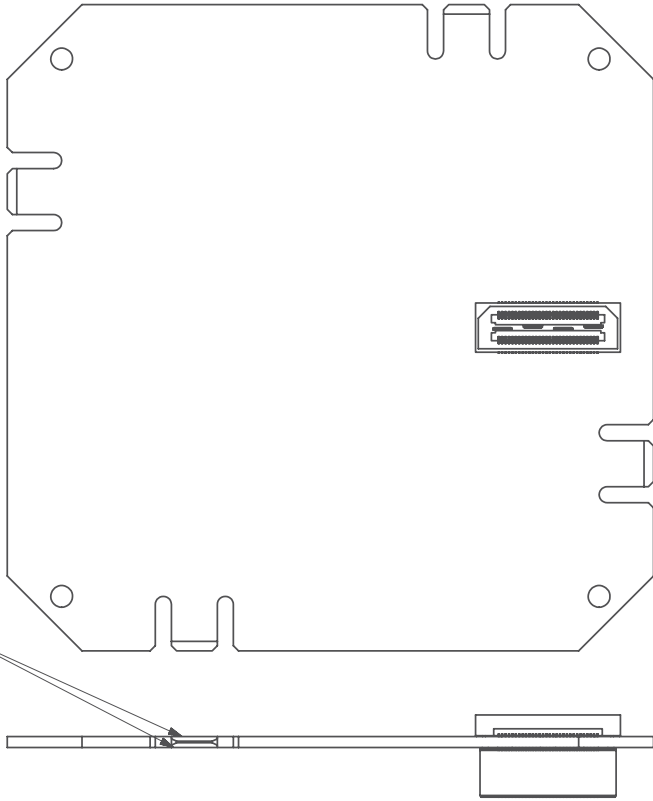


-03 IHU

PCB				
SIZE	DATE	DWG. NO.	REV.	
A	2013-07-19	FOX-ME-113	0.8	
SCALE	1 : 1	UNLESS NOTED OTHERWISE:		
		mm [in]	TOL.	XX ±0.2 XX ±0.1
				SHEET 5 OF 11

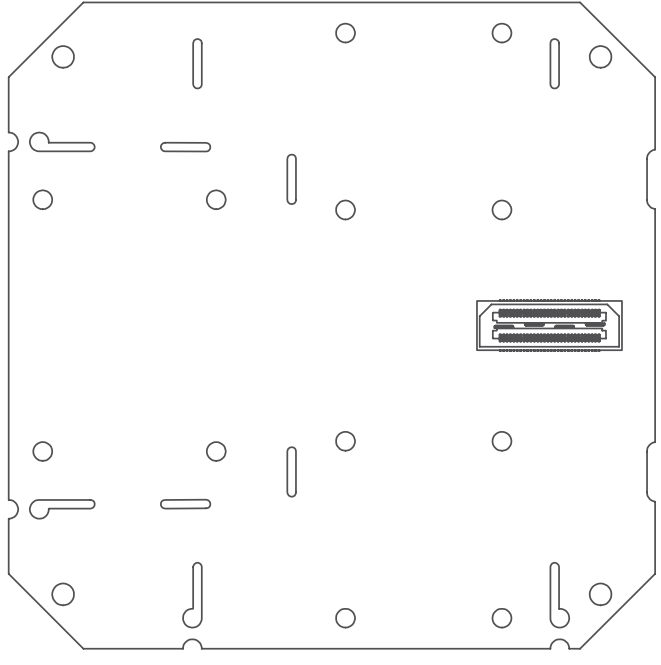
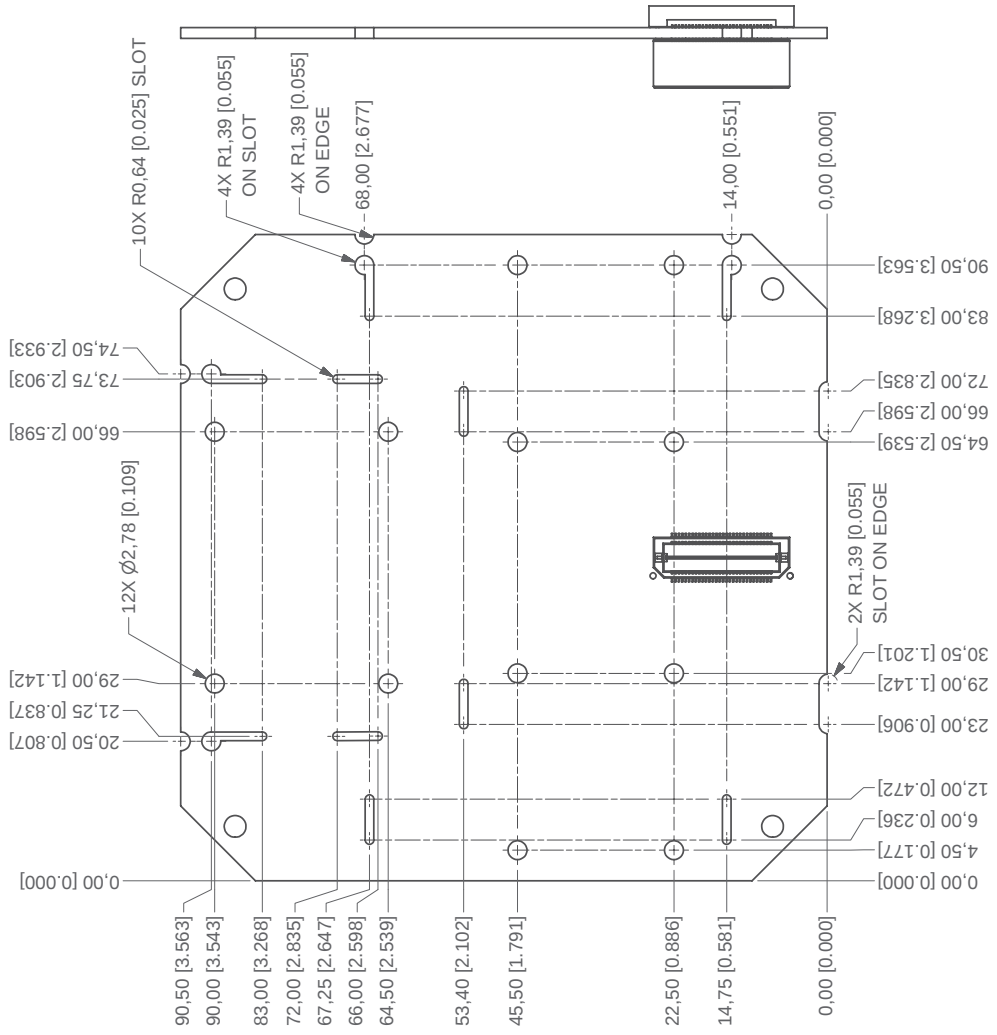


2X CHAMFER 1,40 [0.055] X 0.20 [0.008]
4 PLACES



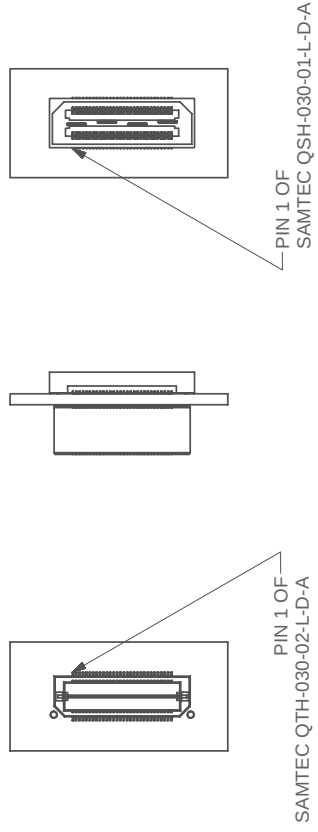
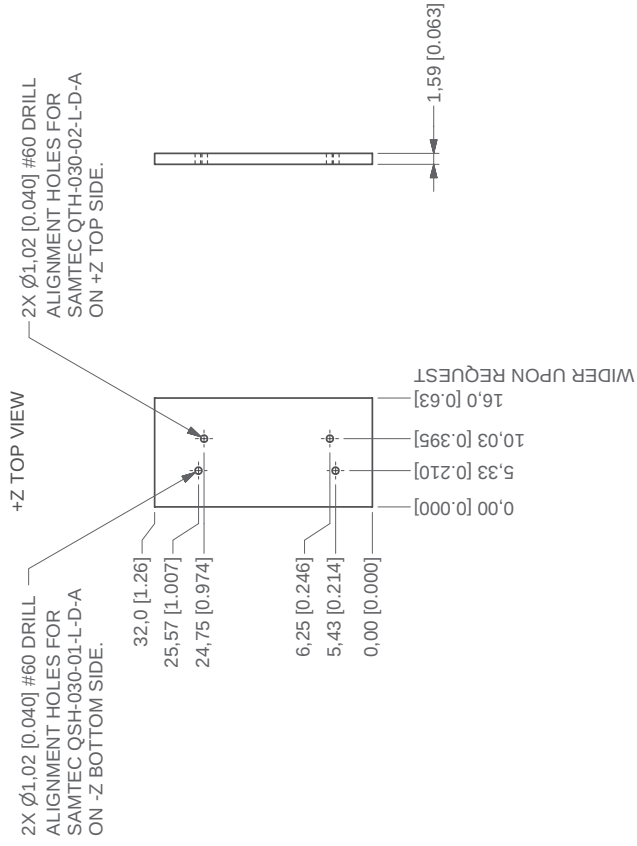
-04 PSU

PCB				
SIZE	DATE	DWG NO.	REV.	
A	2013-07-19	FOX-ME-113	0.8	
SCALE	UNLESS NOTED OTHERWISE:			SHEET
1 : 1	mm [in] TOL. XX ± 0.2 XX ± 0.1			6 OF 11



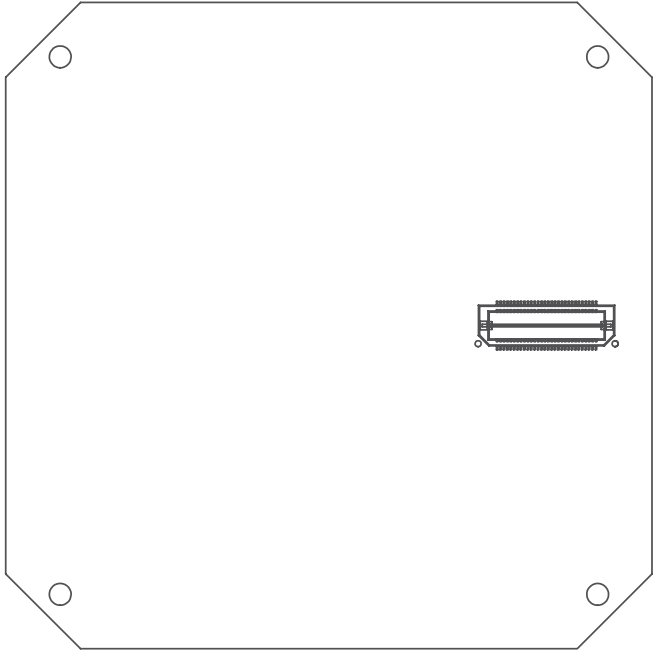
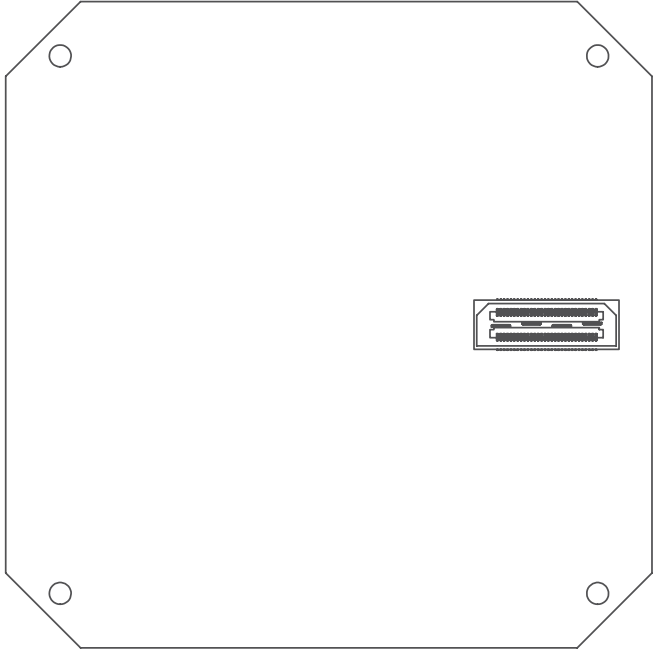
-05 BATTERY #1

PCB			
SIZE	DATE	DWG.NO.	REV.
A	2013-07-19	FOX-ME-113	0.8
SCALE		SHEET	
1 : 1		7 OF 11	
UNLESS NOTED OTHERWISE: mm [in] TOL. XX.XX ± 0.1			



-06 BATTERY #2

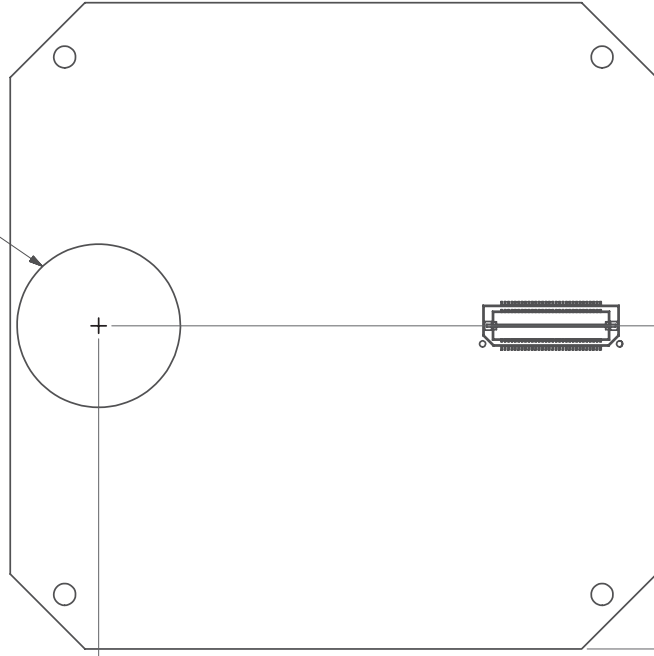
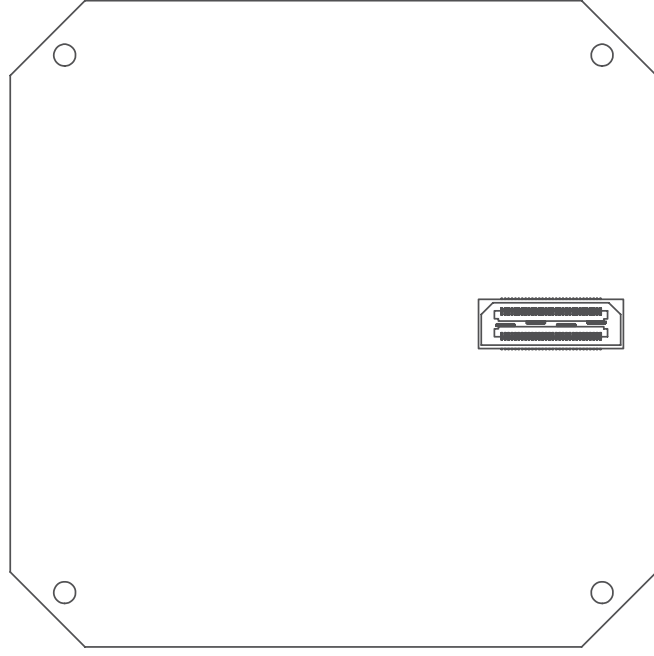
PCB				
SIZE	DATE	DWG. NO.	REV.	
A	2013-07-19	FOX-ME-113	0.8	
SCALE			SHEET	
1 : 1			8 OF 11	
UNLESS NOTED OTHERWISE: mm [in] TOL. XX ± 0.1				



-07 EXPERIMENT #1
-08 EXPERIMENT #2

PCB					
SIZE	DATE	DWG. NO.	REV.	SHEET	
A	2013-07-19	FOX-ME-113	0.8		
SCALE					1 : 1
UNLESS NOTED OTHERWISE:					9 OF 11
mm [in] TOL. XX ± 0.2 XX ± 0.1					

CAMERA BORESIGHT
AND VOLUME PLACEHOLDER



82,00 [3.228]

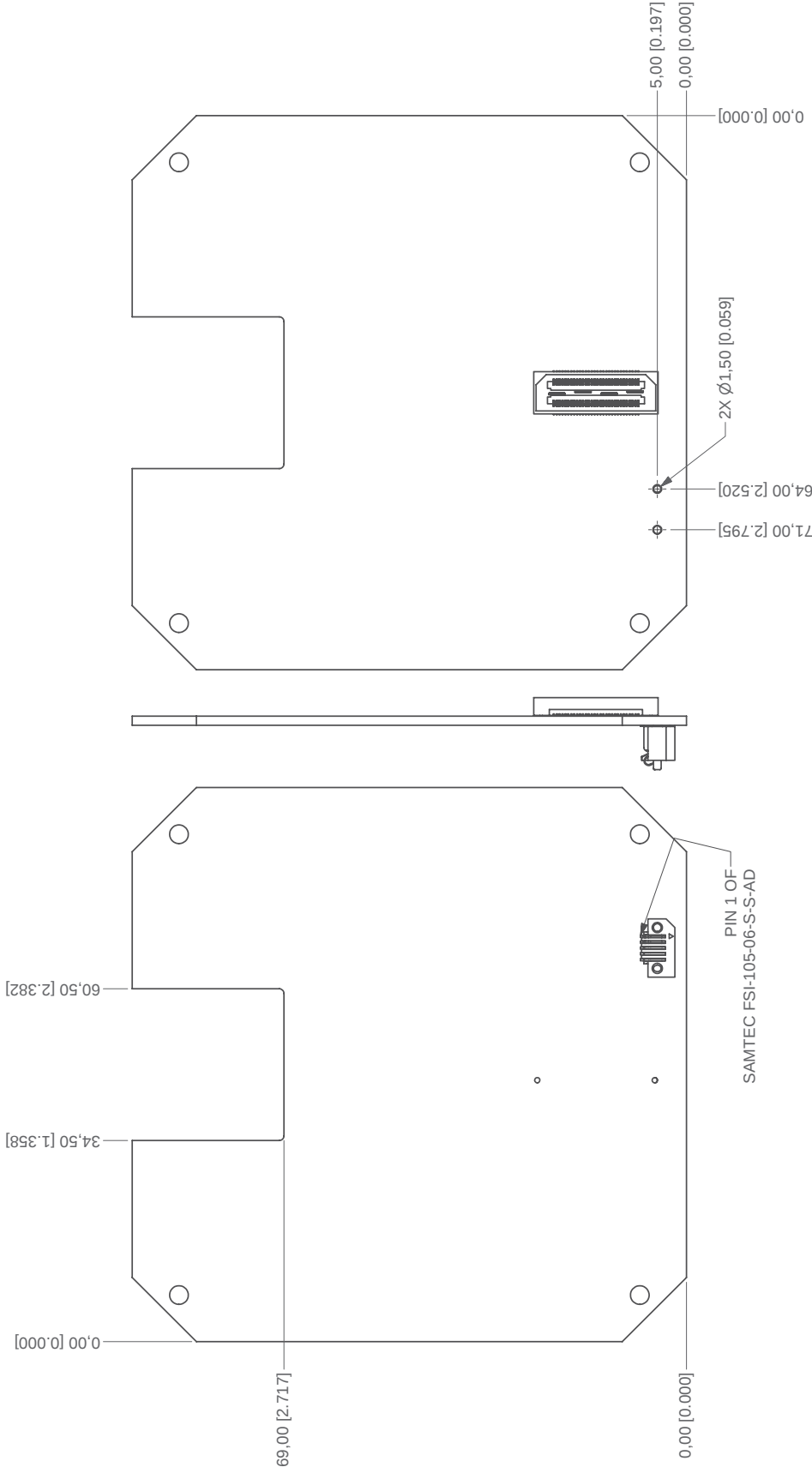
0,00 [0.000]

0,00 [0.000]

47,50 [1.870]

-9 EXPERIMENT #3

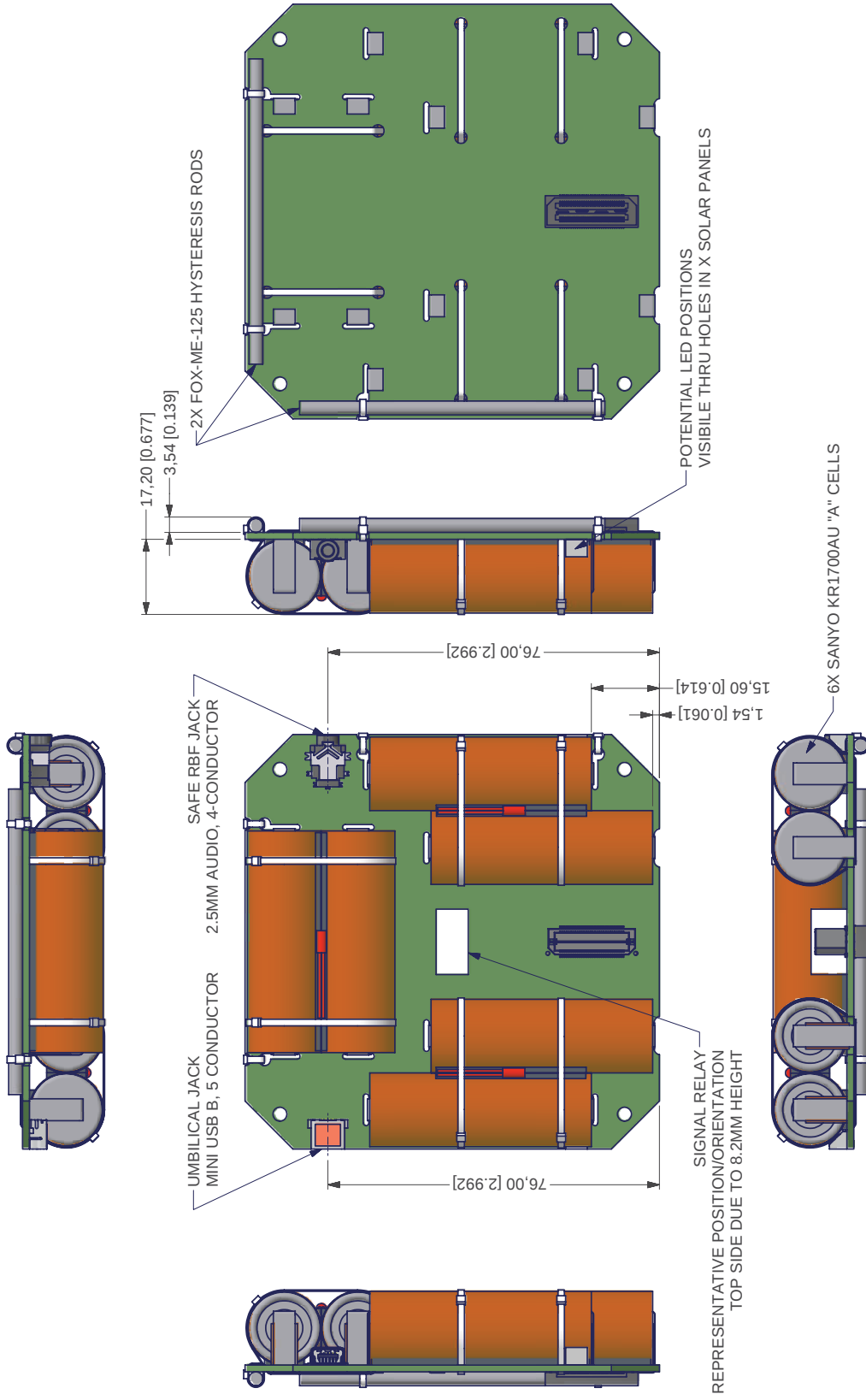
PCB				
SIZE	DATE	DWG. NO.	REV.	
A	2013-07-19	FOX-ME-113	0.8	
SCALE		SHEET		
1 : 1		10 OF 11		
UNLESS NOTED OTHERWISE: mm [in]; TOL. XX.X ± 0.2 XX.XX ± 0.1				



Holes may be added around perimeter of PCB
for ballast masses

-10 EXPERIMENT #4

PCB				
SIZE	DATE	DWG.NO.	REV.	
A	2013-07-19	FOX-ME-113	0.8	
SCALE			SHEET	
1 : 1			11 OF 11	
UNLESS NOTED OTHERWISE: mm [in], TOL. XX ±0.2 XXX ±0.1				

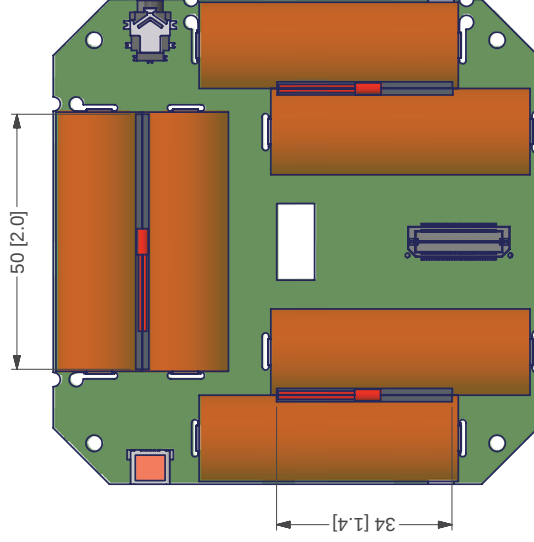
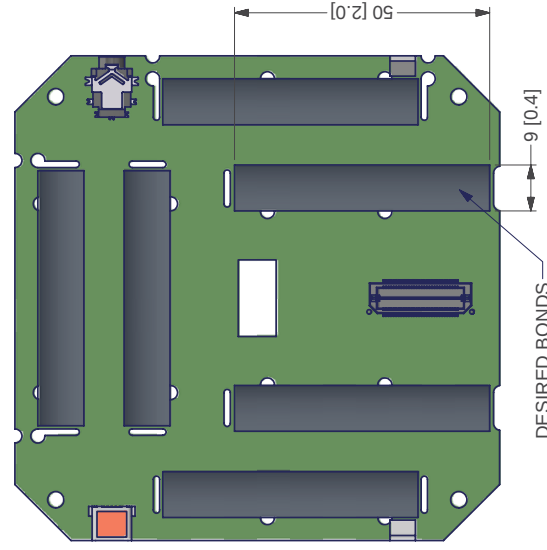
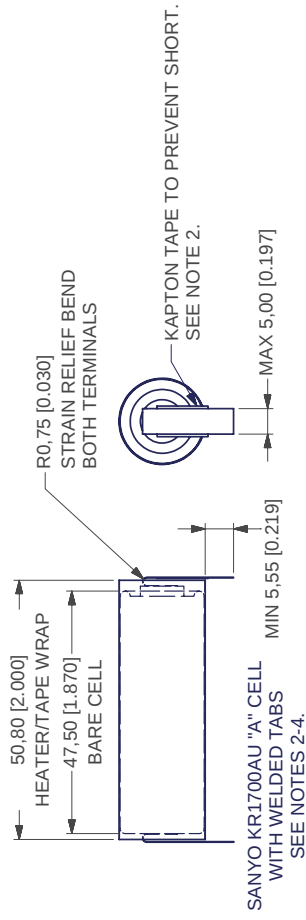




AMSAT
FOX

BATTERY ASSEMBLY

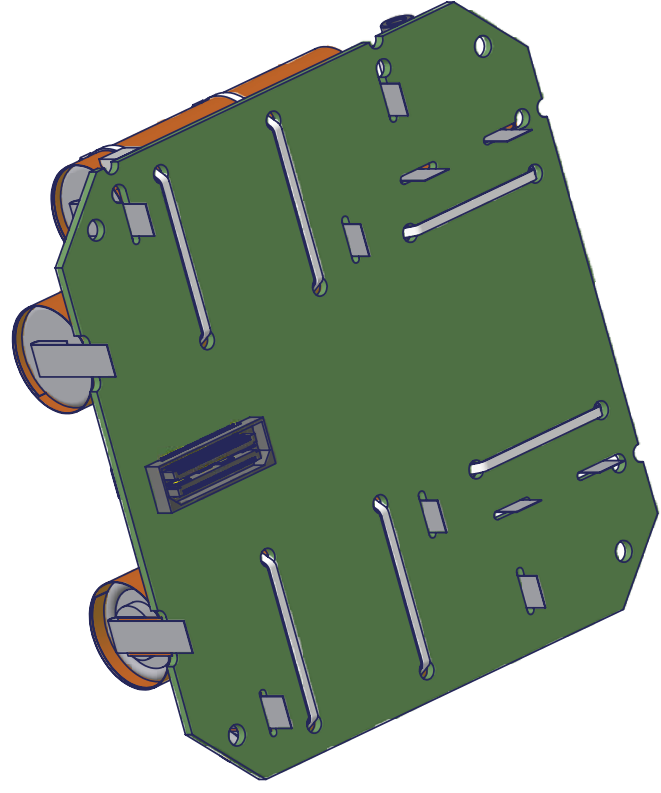
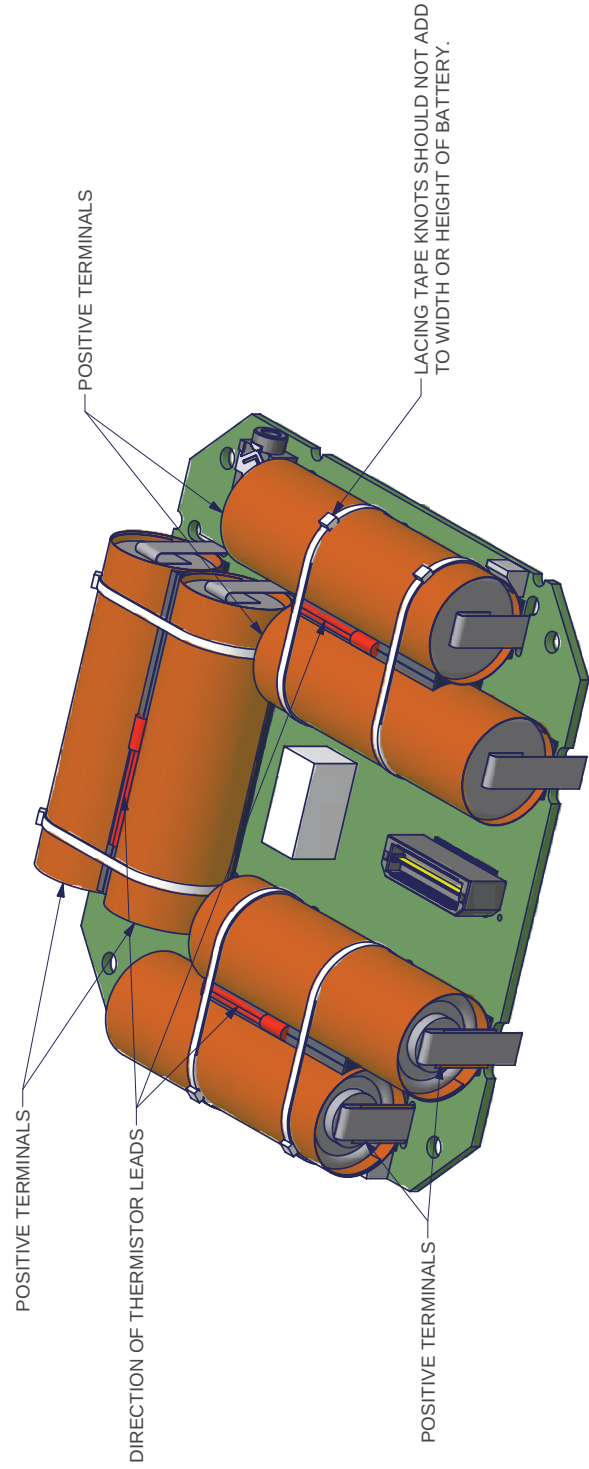
SIZE	DATE	DWG. NO.	REV.
A	2013-09-11	FOX-ME-114	0.3
SCALE			SHEET
3 : 4			1 OF 4
UNLESS NOTED OTHERWISE: mm [in] TOL. X.X ± 0.2 X.XX ± 0.1			



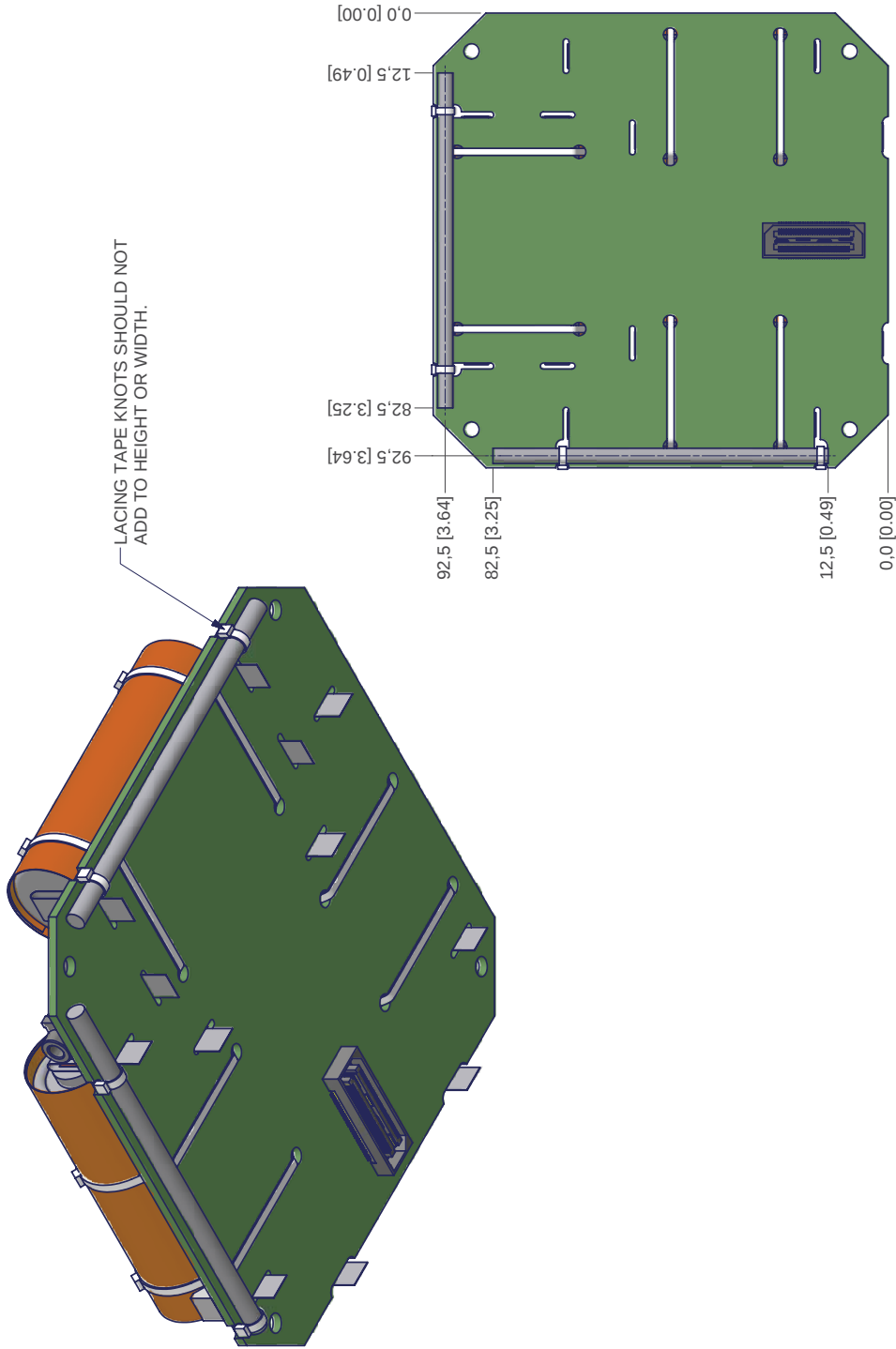
- NOTES:
- 1) SOLDER REFLOW COMPONENTS ON PCB BEFORE BONDING BATTERIES.
 - 2) DO NOT BEND BATTERY TABS UNDER PCB UNTIL ASSEMBLY SOLDER STEP.
 - 3) REMOVE MANUFACTURER'S SHRINK-WRAP LABEL.
APPLY KAPTON TAPE TO POSITIVE TAB TO PREVENT SHORTING TO CASE AFTER BENDING.
CAUTION: TERMINAL SHORTING HAZARD. REMOVE COMPOSITE WASHER ON POSITIVE END.
BEND BOTH TABS 180° FOR STRAIGHT RELIEF.
WIPE WITH ISOPROPYL ALCOHOL.
 - 4) APPLY KAPTON HEATER OMEGA KHLV-102/5-P. WRAPS APPROX 1/2 OF SURFACE AREA.
DO NOT APPLY BETWEEN CELLS OR BETWEEN CELLS AND PCB.
CLOCKING AROUND PERIMETER TBD. ORIENTATION OF LEADS TBD.
 - 5) WRAP CELL WITH 1 LAYER OF 2 INCH WIDE 1 MIL PERMACEL P224 KAPTON POLYIMIDE TAPE WITH ACRYLIC ADHESIVE.
 - 6) PREPARE KAPTON WRAPPED SURFACE OF CELL FOR BONDING BY ACETONE SOLVENT CLEANING.
 - 7) USE HYSOL/LOCTITE EPOXI-PATCH 9340 TO BOND PAIRS OF CELLS, AND CELLS TO PCB. WET BOTH MATING SURFACES.
SECURE WITH LACTING TAPE BREYDEN 104-3 IF POT LIFE PERMITS, OTHERWISE USE TEMPORARY 0.032" WIDE X 4" LONG ZIP TIES.
KEEP HOLES CLEAR OF EPOXY.
PRESS LEADED THERMISTOR INTO EPOXY. DIRECTION OF LEADS AS SHOWN.
CURE ROOM TEMPERATURE FOR 24 HOURS, OR 50°C (122°F) FOR 6 HOURS.

BATTERY ASSEMBLY

SIZE	DATE	DATE	REV
A	2013-09-11	FOX-ME-114	0.3
SCALE	3 : 4	UNLESS NOTED OTHERWISE:	SHEET 2 OF 4
		mm [in] TOL. XX.XX ± 0.1	

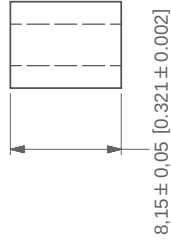
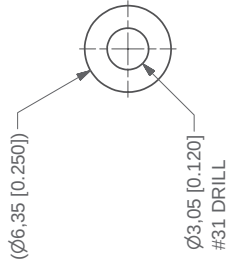


BATTERY ASSEMBLY				
SIZE	DATE	DWG. NO.	REV.	
A	2013-09-11	FOX-ME-114	0.3	
SCALE	1 : 1	UNLESS NOTED OTHERWISE:		
		mm [in]	TOL.	XX ±0.2 XX ±0.1
			SHEET	3 OF 4



- NOTES:
- 8) WRAP PERIMETER OF 2X FOX-ME-125 HYSTERESIS RODS WITH 1 LAYER OF 1 MIL PERMACEL P224 KAPTON POLYIMIDE TAPE WITH ACRYLIC ADHESIVE.
 - 9) PREPARE KAPTON WRAPPED SURFACE OF RODS FOR BONDING BY ACETONE SOLVENT CLEANING.
 - 10) BOND RODS USING HYSOL/LOCTITE EPOXI-PATCH 9340. SECURE WITH BREYDEN 204-3 LACING TAPE. PLACE KNOT TO PREVENT INCREASING HEIGHT ABOVE PCB.
 - CURE ROOM TEMPERATURE FOR 24 HOURS, OR 50°C (122°F) FOR 6 HOURS.
 - 11) SECURE ALL KNOTS WITH TBD URALANE.

BATTERY ASSEMBLY				
SIZE	DATE	DWG. NO.	REV.	
A	2013-09-11	FOX-ME-114	0.3	
SCALE	UNLESS NOTED OTHERWISE:			
VARIES	mm [in]	TOL.	XX ±0.2 XX ±0.1	SHEET 4 OF 4

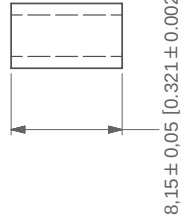
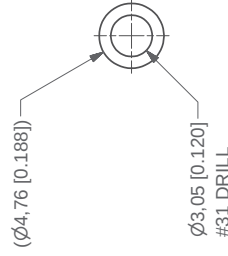


-01 AL SPACER

MAT'L: ALUMINUM 6061-T6
MAKE FROM MCMaster-CARR 8974K31 ROD.
CHEMICAL CONVERSION COAT PER MIL-C-5541
CLASS 3, ELECTRICALLY CONDUCTIVE CLEAR.

-07 DELRIN SPACER

MAT'L: BLACK DELRIN
MAKE FROM MCMaster-CARR 8576K11 ROD.

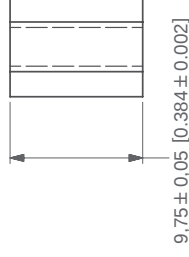
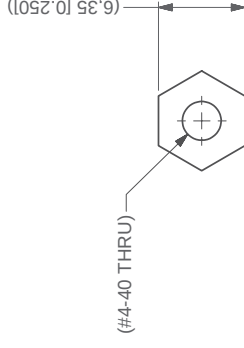


-03 CU SPACER FOR MOUNT

MAT'L: COPPER ALLOY 110 H04 (HARD)
MAKE FROM MCMaster-CARR 8966K88 ROD.
GOLD PLATE.

-09 DELRIN SPACER FOR MOUNT

MAT'L: BLACK DELRIN
MAKE FROM MCMaster-CARR 8576K11 ROD.



-05 AL THREADED SPACER

MAT'L: ALUMINUM 6061-T6
MAKE FROM MCMaster-CARR 91780A427 STANDOFF.
CHEMICAL CONVERSION COAT PER MIL-C-5541
CLASS 3, ELECTRICALLY CONDUCTIVE CLEAR.

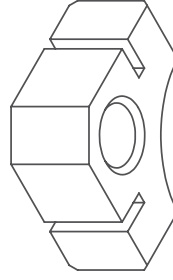
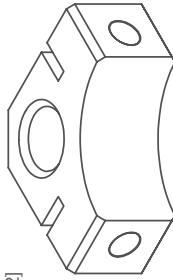


AMSAT

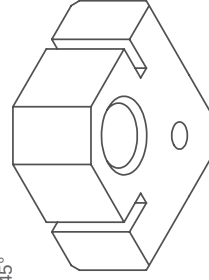
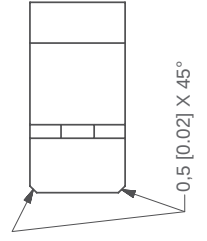
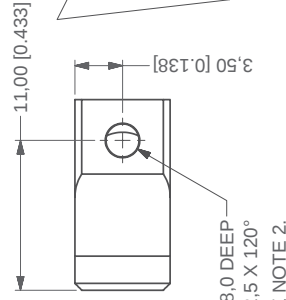
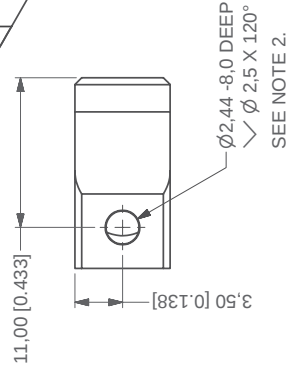
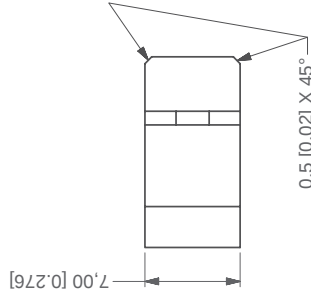
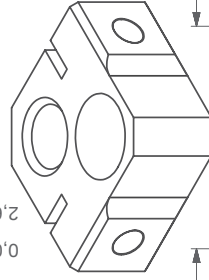
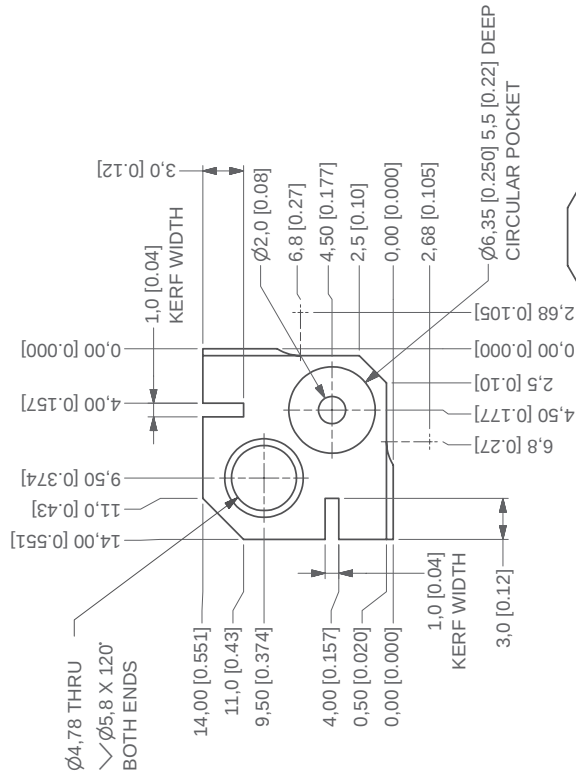
FOX

PCB SPACER

SIZE	DATE	DWG. NO.	REV.
A	2013-08-24	FOX-ME-117	0.5
SCALE			SHEET
2 : 1			1 OF 1
UNLESS NOTED OTHERWISE: mm [in] TOL. X.X ± 0.2 X.XX ± 0.1			

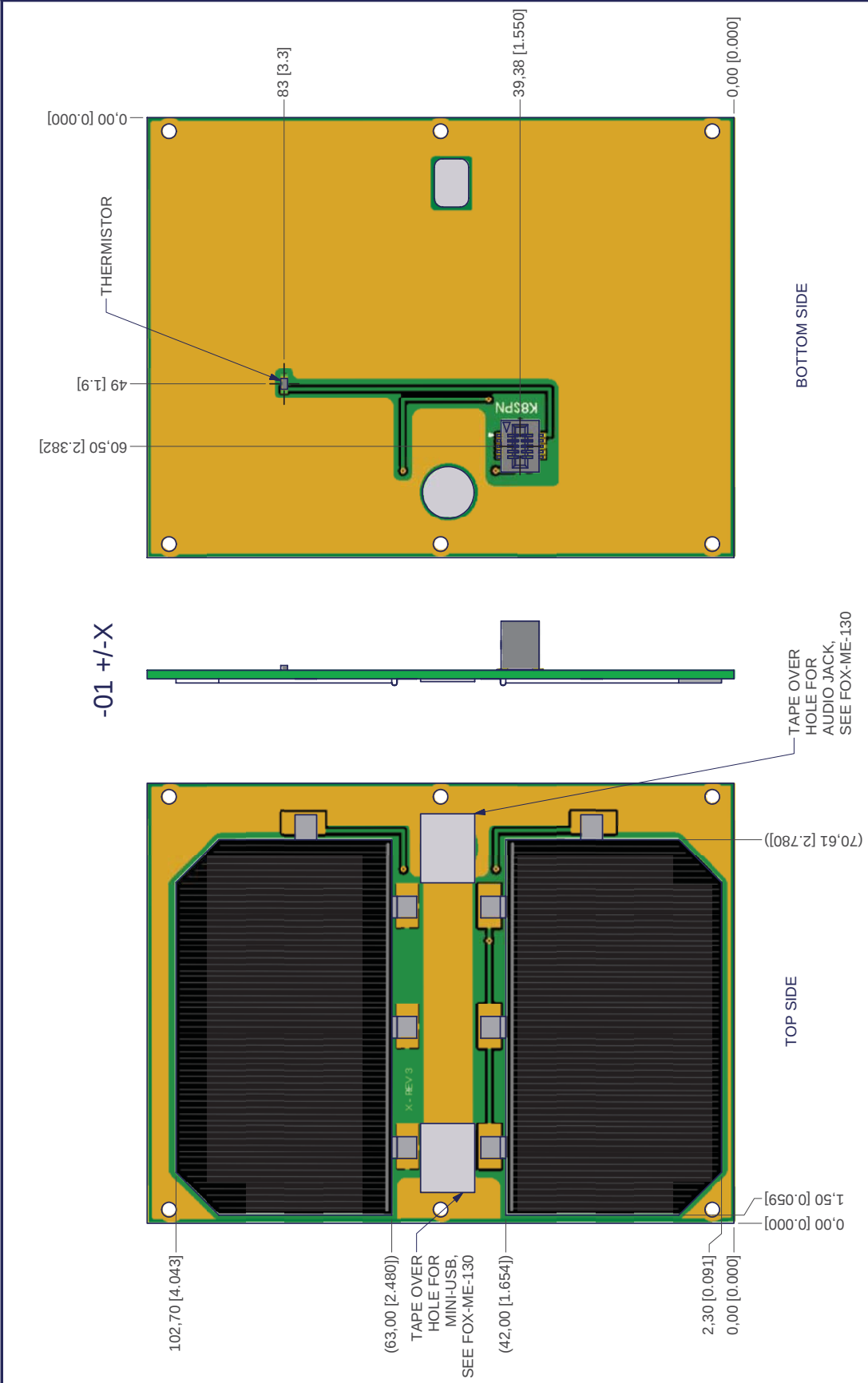


SIZE	DATE	DWG. NO.	REV.
A	2013-03-27	FOX-ME-118	0.6



-03

PCB DELRIN MOUNT				
SIZE	DATE	DWG. NO.	REV.	
A	2013-03-27	FOX-ME-118	0.6	
SCALE	2 : 1	UNLESS NOTED OTHERWISE:		
		mm [in] TOL. XX ±0.2 XX ±0.1		
			SHEET	2 OF 2





AMSAT

FOX

X SIDE SOLAR PANEL

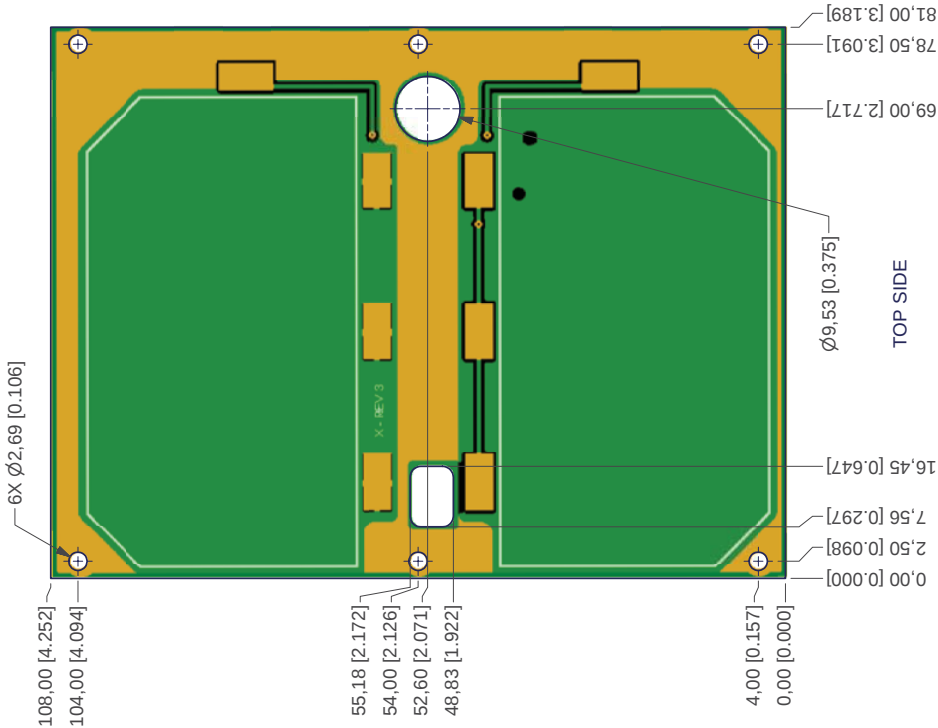
DATE	DWG. NO.	REV.
2013-06-11	FOX-ME-119	0.8
SCALE	SHEET	
1 : 1	1 OF 3	

UNLESS NOTED OTHERWISE:

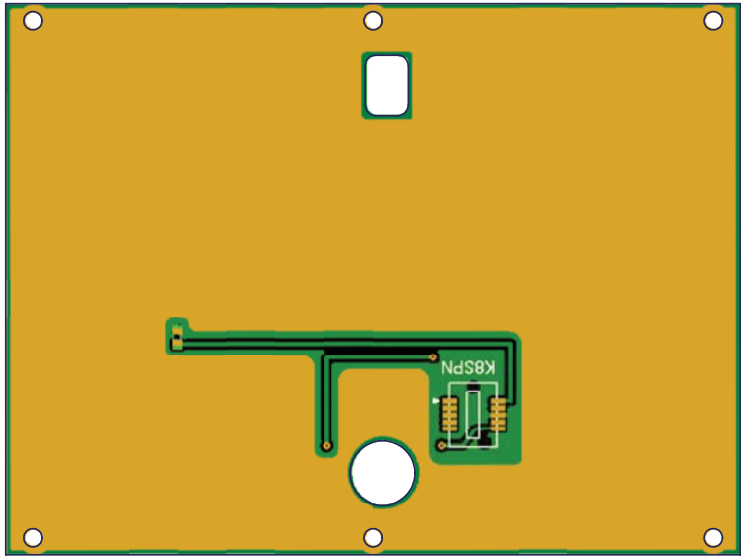
mm [in] TOL. X.X ± 0.2 X.XX ± 0.1

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	FOX-ME-119-05	PCB
3	1	SAMTEC MEC1-105-02-S-D-NP-A	EDGE CARD CONNECTOR
4	1		THERMISTOR, 0805
5	2		1ST SURF METAL TAPE
7	2	FOX-ME-122	SpaceQuest UTJ
PARTS LIST			DESCRIPTION

-05 PCB



TOP SIDE



BOTTOM SIDE

NOTES:
1) FLASH GOLD TOP AND BOTTOM SIDES, ANY AVAILABLE AREA.

AMSAT
FOX

X SIDE SOLAR PANEL

SIZE	DATE	DWG. NO.	REV.
A	2013-06-11	FOX-ME-119	0.8
SCALE	1 : 1	UNLESS NOTED OTHERWISE:	SHEET
		mm [in] TOL. X.X $\pm$ 0.2 X.XX $\pm$ 0.1	3 OF 3

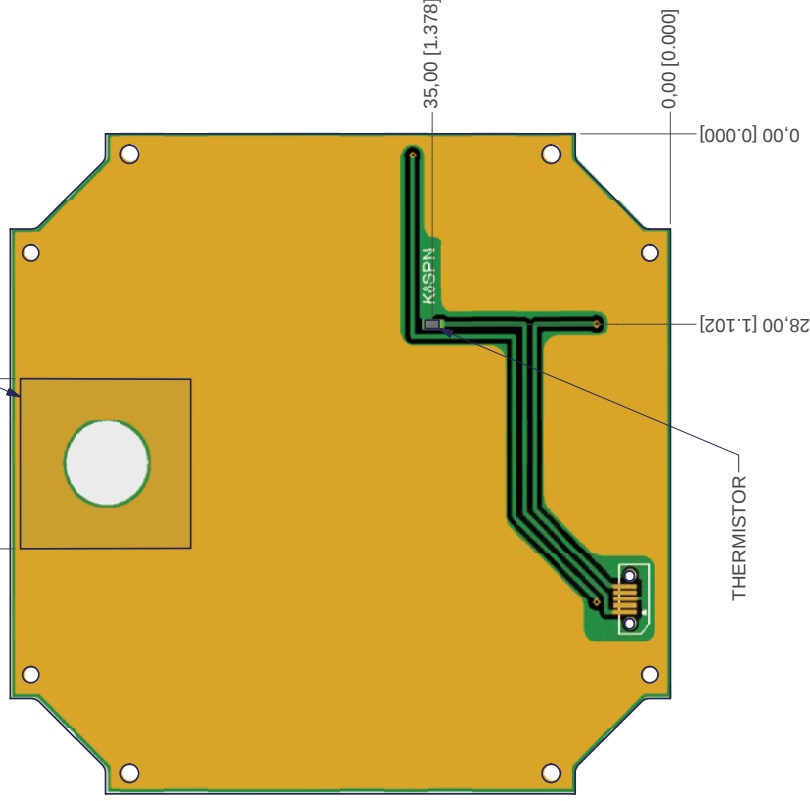
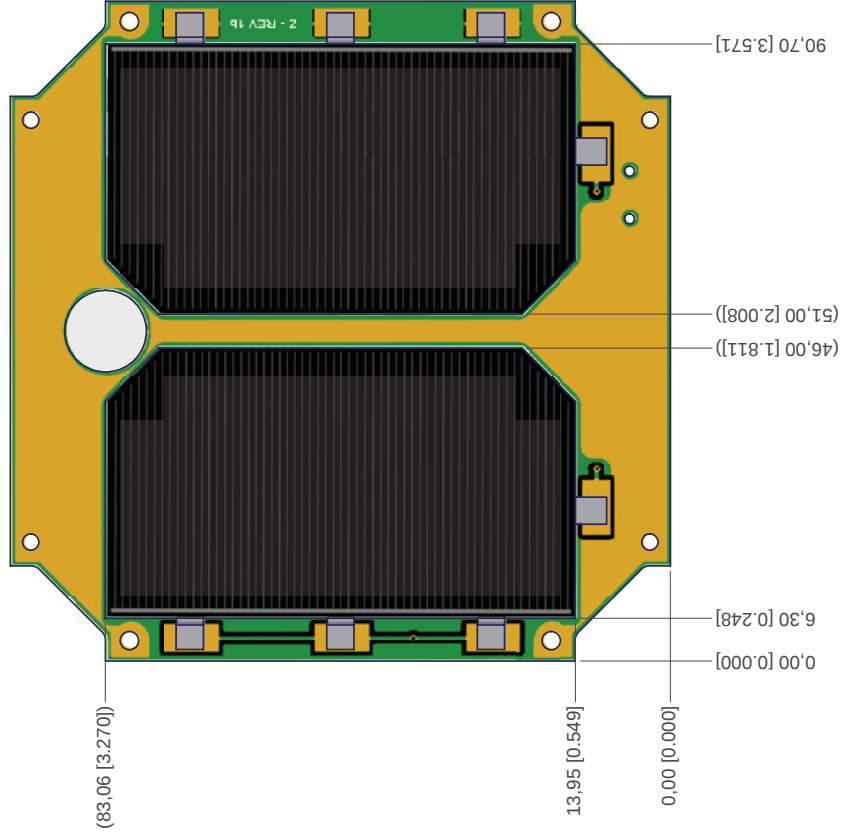
-01
+Z TOP

TOP SIDE

BOTTOM SIDE

COVER HOLE WITH TBD IR FILTER
USING TBD COMPOUND

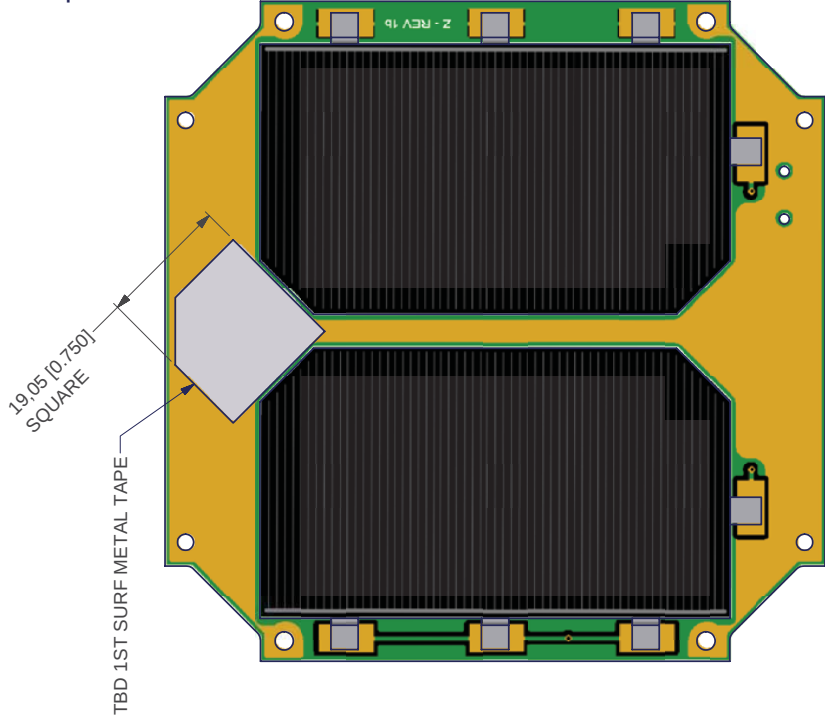
25 [1.0]
SQUARE



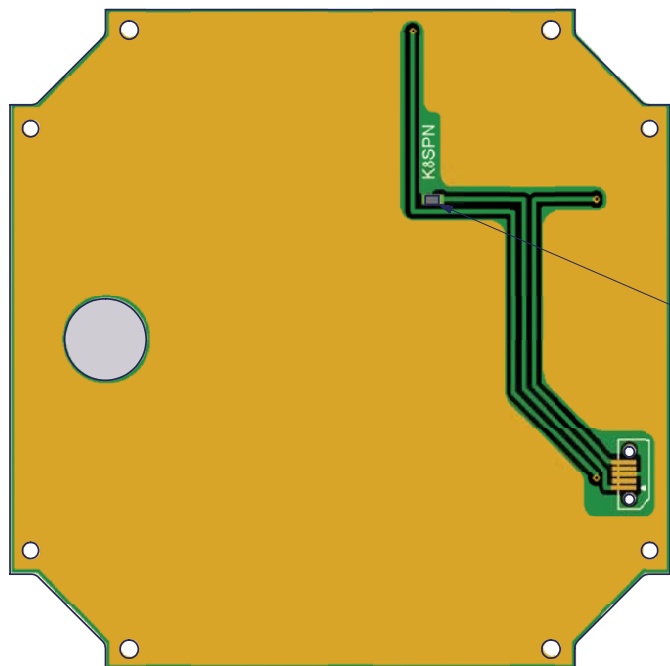
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	FOX-ME-120-03	PCB
6	2	FOX-ME-122	SpaceQuest UTJ
7	1		THERMISTOR, 0805
9	1		IR FILTER
Parts List			DESCRIPTION

AMSAT FOX			
Z TOP/BOTT SOLAR PANEL			
SIZE	DATE	DWG. NO.	REV.
A	2013-06-12	FOX-ME-120	0.9
SCALE	1 : 1	UNLESS NOTED OTHERWISE:	SHEET
		mm [in] TOL. X.X ± 0.2 X.XX ± 0.1	1 OF 3

-03
-Z BOTTOM



TOP SIDE



THERMISTOR

BOTTOM SIDE

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	FOX-ME-120-03	PCB
6	2	FOX-ME-122	SpaceQuest UTJ
7	1		THERMISTOR, 0805
8	1		1ST SURF METAL TAPE
Parts List			



AMSAT
FOX

Z TOP/BOTT SOLAR PANEL

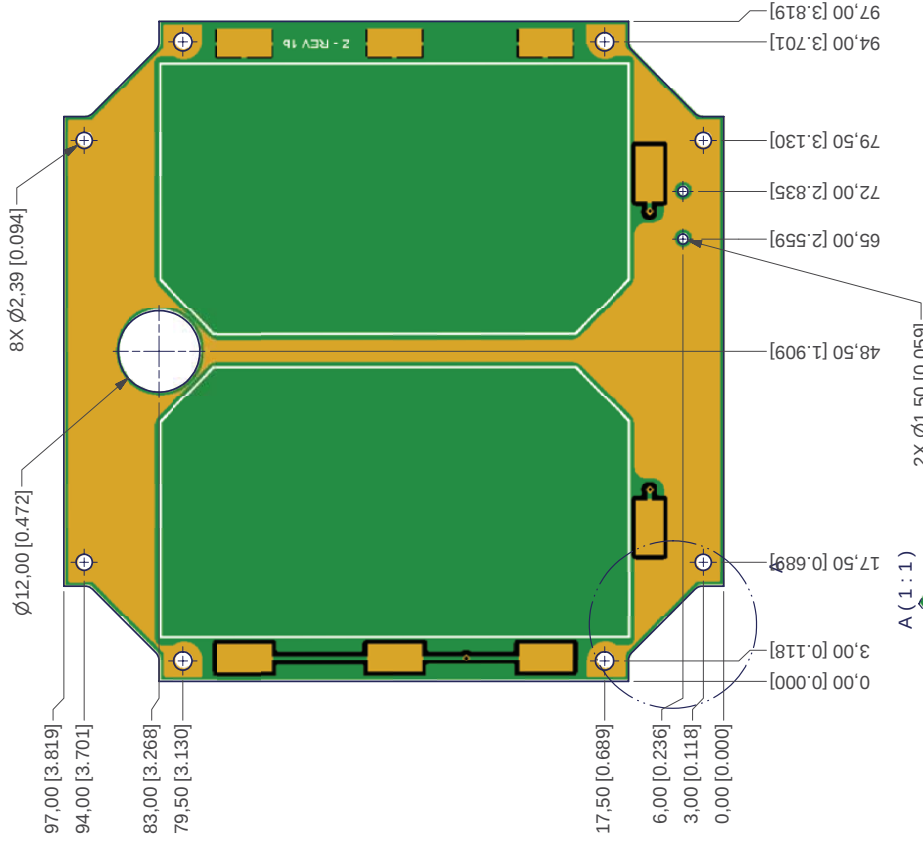
DATE	DWG.NO	REV.
2013-06-12	FOX-ME-120	0.9
SCALE	1 : 1	SHEET 2 OF 3

UNLESS NOTED OTHERWISE:
mm [in] TOL. X.X ± 0.2 X.XX ± 0.1

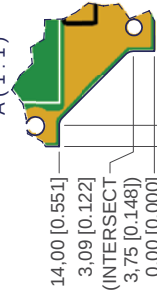
-05
PCB

TOP SIDE

BOTTOM SIDE



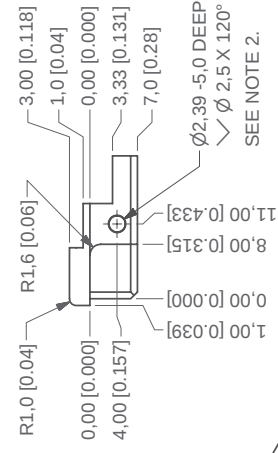
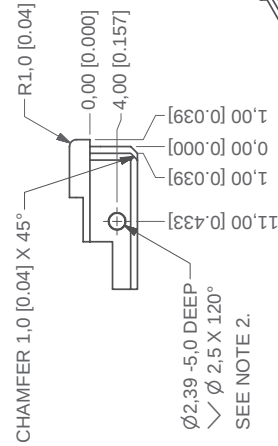
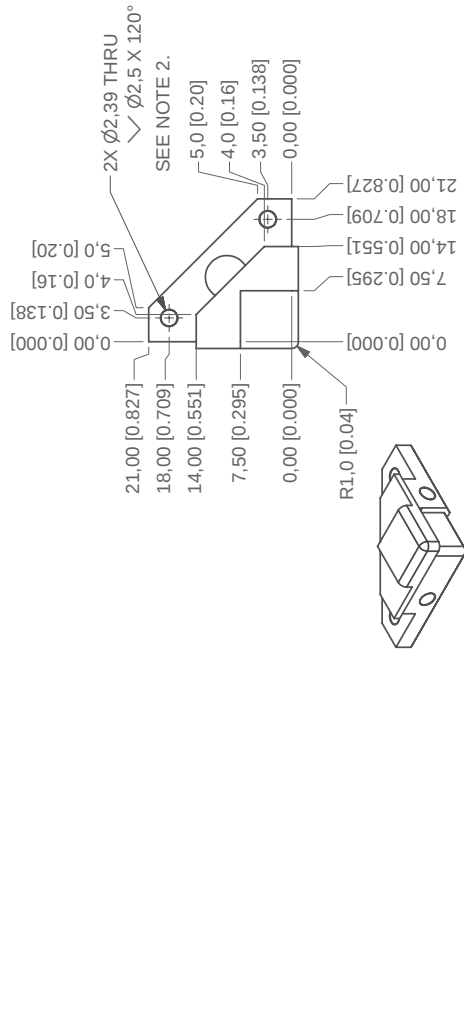
A (1:1)



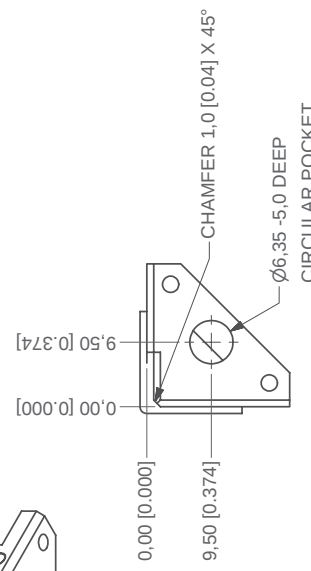
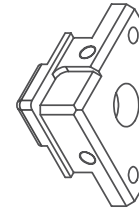
- NOTES:
- 1) PLATING FINISH: GOLD-ENIG TOP & BOTTOM SIDES.
 - 2) BOTTOM SIDE, SELECTIVE GOLD FIVE PADS OF CONNECTOR 30 MILS.

AMSAT
FOX

Z TOP/BOTT SOLAR PANEL			
SIZE	DATE	DWG. NO.	REV.
A	2013-06-12	FOX-ME-120	0.9
SCALE			SHEET
1 : 1			3 OF 3

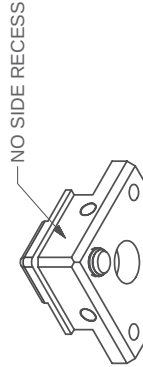
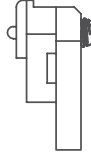
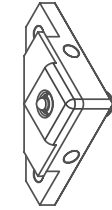
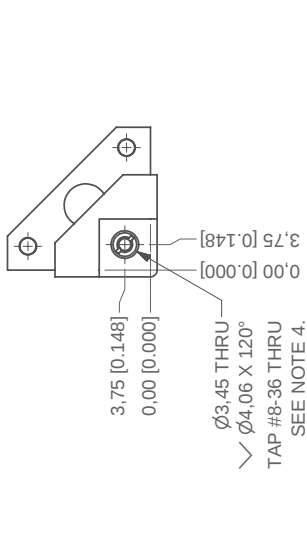


-01 +Z



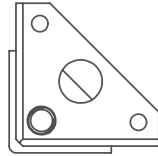
- NOTES:
- 1) -01, -03, -09 MATERIAL: 6061-T6
 - 2) STI TAP #2-56 MIN ∇ 4, USING HELICOIL BOTTOMING TAP 02CBB. INSTALL HELICOIL #2-56 X 1 DIA 358502CN0086, USING HELICOIL INSTALLATION TOOL 551-02. REMOVE TANG USING HELICOIL TANG-BREAKOFF TOOL 3695-02.
 - 3) -01, -03, -09: CHEMICAL CONVERSION COAT PER MIL-DTL-5541 CLASS 3, ELECTRICALLY CONDUCTIVE CLEAR.

AMSAT FOX		RAIL ENDS	
DATE	DWG. NO.	REV.	
A	2013-06-06	FOX-ME-121	1.1
SCALE	1 : 1	UNLESS NOTED OTHERWISE:	SHEET
		mm [in] TOL. X.X ± 0.2 X.XX ± 0.1	1 OF 6



-03 -Z W/SPRING

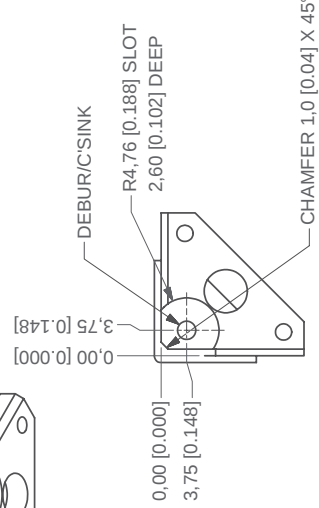
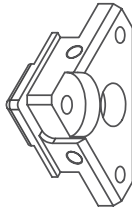
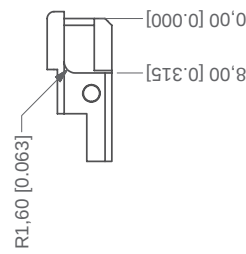
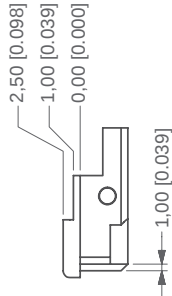
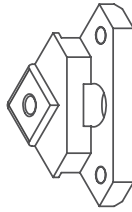
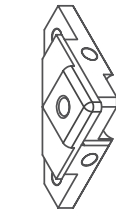
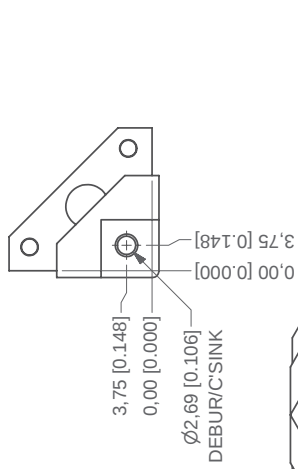
MAKE SIMILAR TO -01 EXCEPT AS NOTED



- NOTES:
- INSTALL MCMMASTER-CARR 84985A76 SPRING PLUNGER W/LOCK ELEMENT, USING SPANNER WRENCH 3382A12. SPRING HOUSING FLUSH WITH ALUMINUM; BUTTON PROTRUDES ABOVE TOP, AND TAIL PROTRUDES OUT BOTTOM.

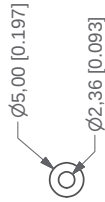
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	FOX-ME-121-03	RAIL END, -Z W/SPRING
2	1	MCMMASTER 84985A76	SPRING PLUNGER W/LOCK, #8-36 LONG
Parts List			

RAIL ENDS			
SIZE	DATE	DWG NO.	REV
A	2013-06-06	FOX-ME-121	1.1
SCALE	1 : 1	UNLESS NOTED OTHERWISE: mm [in], TOL. XX.X ± 0.2 XX.X ± 0.1	
			SHEET 2 OF 6



-09 -Z W/ PLUNGER HOLE
MAKE SIMILAR TO -01 EXCEPT AS NOTED

RAIL ENDS				
SIZE	DATE	DWG. NO.	REV.	
A	2013-06-06	FOX-ME-121	1.1	
SCALE		SHEET		
1 : 1		5 OF 6		
UNLESS NOTED OTHERWISE: mm [in] TOL. XX ±0.2 XX ±0.1				

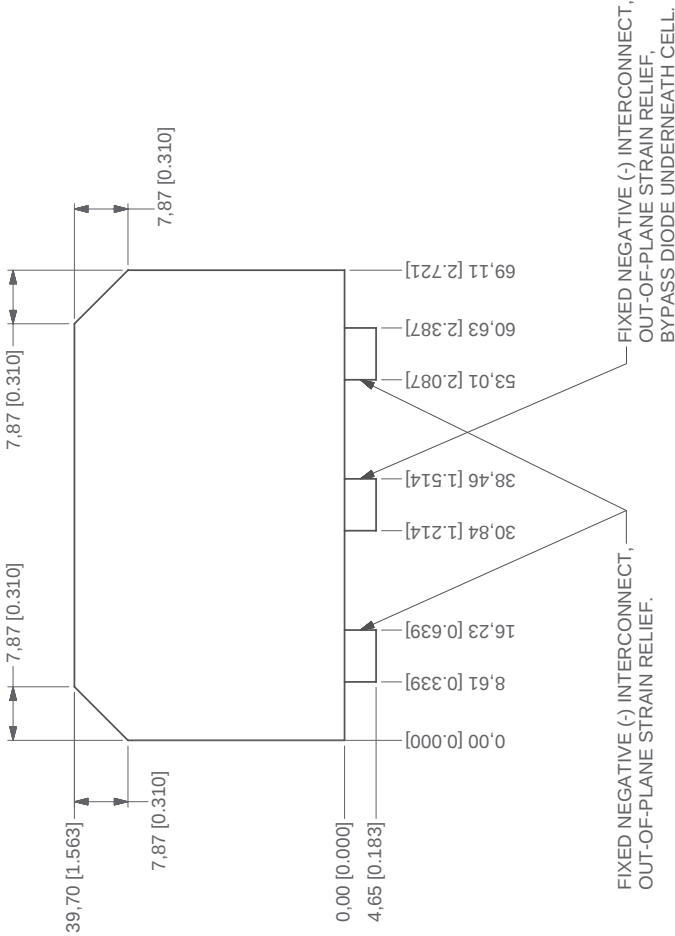


-11 SWITCH PLUNGER

NOTES:
5) -11 MATERIAL: BALCK DELRIN

RAIL ENDS				
SIZE	DATE	DWG NO.	REV.	
A	2013-06-06	FOX-ME-121	1.1	
SCALE		SHEET		
1 : 1		6 OF 6		
UNLESS NOTED OTHERWISE: mm [in]; TOL. X.X ±0.2 X.XX ±0.1				

-01 C1C



- NOTES:
- 1) SOURCE: SPACEQUEST, LTD. FAIRFAX, VA.
 - 2) MATERIALS/PRODUCTS:
SOLAR CELL: SPECTROLAB UTJ, 28.3% 26.62CM²
RTV: TBD
COVERGLASS: CERIA-DOPED GLASS
INTERCONNECT: INVAR/KOVAR
 - 3) APPLICATION NOTES:
KEEP-OUT ZONE 1MM ALL SIDES TO PANEL EDGE, SOLDER PAD OR TRACE.
BONDED TO PCB USING NUSIL CV-2289-1 RTV OR EQUIVALENT.
FLOATING POSITIVE (+) INTERCONNECTS AN BE ADDED TO ANY OTHER EDGE.



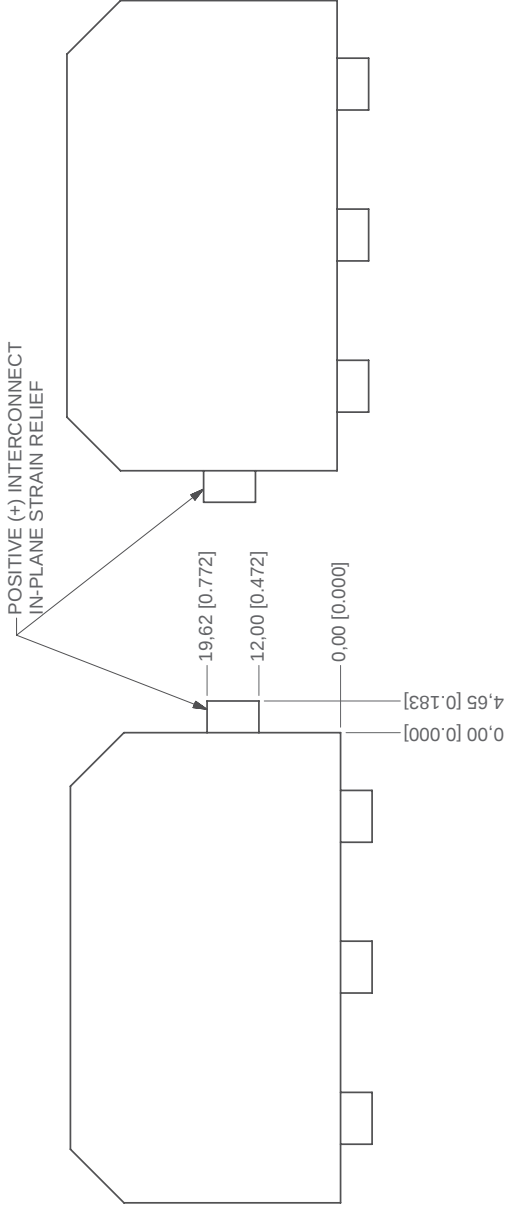
AMSAT
FOX

UTJ CELL ICD

SIZE	DATE	DWG. NO.	REV.
A	2013-06-04	FOX-ME-122	0.2
SCALE	1 : 1	UNLESS NOTED OTHERWISE:	SHEET
		mm [in] TOL. XX ± 0.2 XX ± 0.1	1 OF 2

-03 CIC W/ POSITIVE INTERCONNECT

-04 CIC W/ POSITIVE INTERCONNECT



AMSAT
FOX

UTJ CELL ICD

SIZE	DATE	DWG. NO.	REV.
A	2013-06-04	FOX-ME-122	0.2
UNLESS NOTED OTHERWISE:			SHEET
SCALE	1 : 1	mm [in] TOL. X.X ± 0.2 X.XX ± 0.1	2 OF 2

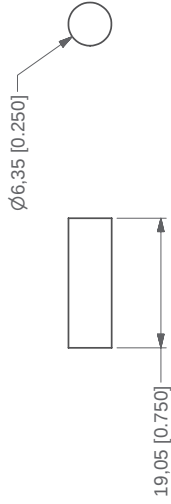


- NOTES:
- 1) MATERIAL: 316 STAINLESS STEEL
 - 2) MAKE FROM GRAINGER 21YN73 OR EQUIVALENT.

AMSAT

FOX

THREADED ROD			
SIZE	DATE	DWG. NO.	REV.
A	2013-08-16	FOX-ME-123	0.2
SCALE			SHEET
1 : 1			1 OF 1
UNLESS NOTED OTHERWISE: mm [in] TOL. XX ± 0.2 XXX ± 0.1			



AMSAT
FOX



MAGNET

SIZE	DATE	DWG.NO	REV.
A	2013-05-22	FOX-ME-124	0.1
SCALE			SHEET
1 : 1			1 OF 1
UNLESS NOTED OTHERWISE: mm [in] TOL. XX ± 0.2 XXX ± 0.1			



AMSAT

FOX

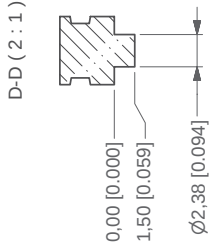
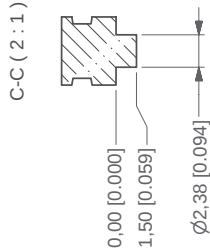
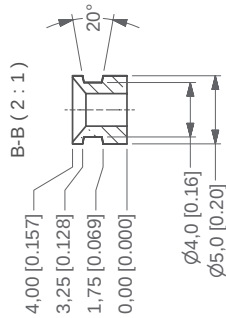
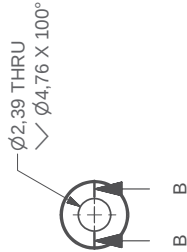


HYSTERESIS ROD

SIZE	DATE	DWG. NO.	REV.
A	2013-05-22	FOX-ME-125	0.1
SCALE			SHEET
1 : 1			1 OF 1

UNLESS NOTED OTHERWISE:

mm [in] TOL. X.X ± 0.2 X.XX ± 0.1



-01
DELETED

-03
BLACK DELRIN,
MCMaster-CARR 8576K11

-05
DIMS SAME AS -03 EXCEPT AS NOTED.
COPPER ALLOY 110 H04 (HARD),
MCMaster-CARR 8966K423.
GOLD PLATED.

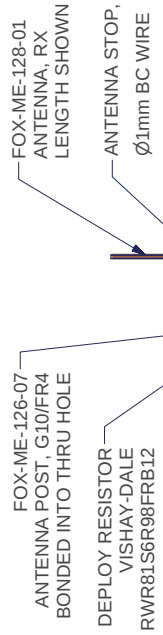
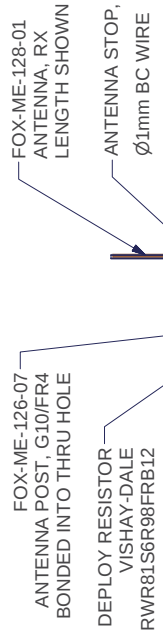
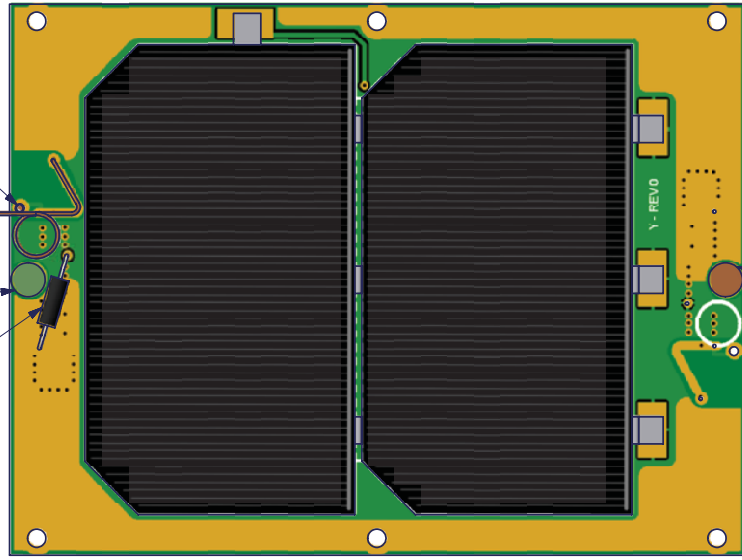
-07
DIMS SAME AS -03 EXCEPT AS NOTED.
G10/FR4 ROD,
MCMaster-CARR 8669K891
OR EQUIVALENT.

FOX-ME-126-07
ANTENNA POST, G10/FR4
BONDED INTO THRU HOLE

FOX-ME-128-01
ANTENNA, RX
LENGTH SHOWN

DEPLOY RESISTOR
VISHAY-DALE
RWR81S6F98FRB12

ANTENNA STOP,
Ø1mm BC WIRE

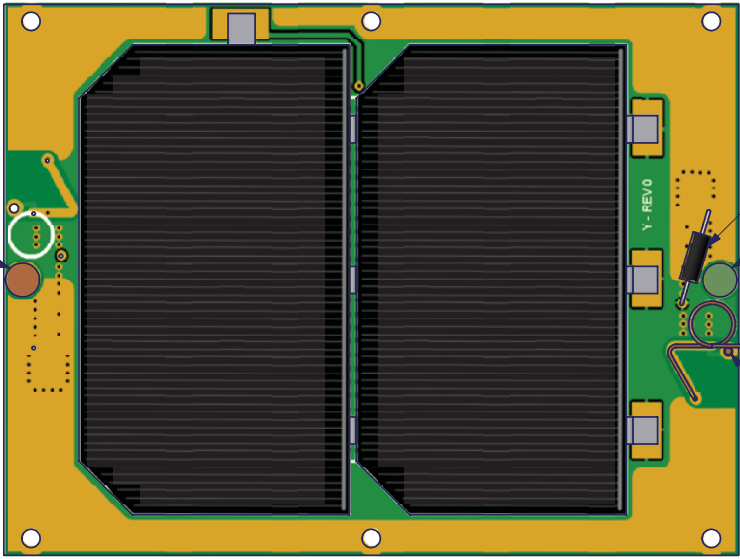


27
BOTTOM SIDE



-03 -Y (144 TX ANTENNA POINTING IN -Z)

FOX-ME-126-05
ANTENNA POST, COPPER
SOLDERED INTO THRU HOLE



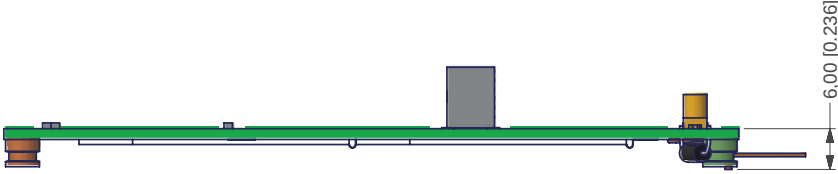
ANTENNA STOP,
Ø1MM BC WIRE

FOX-ME-128-03
ANTENNA, TX
LENGTH SHOWN CROPPED

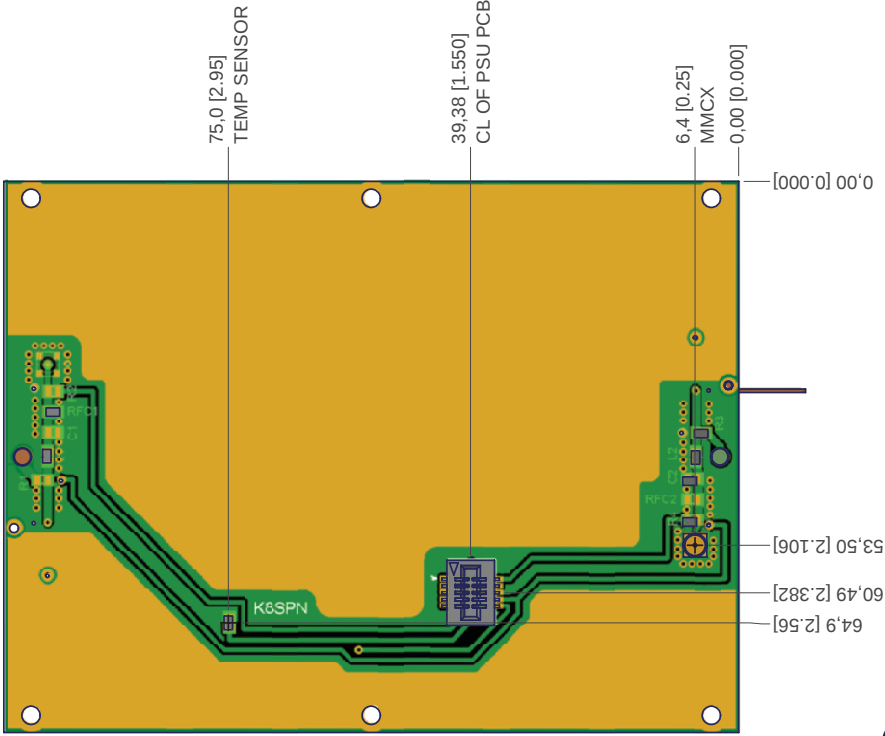
DEPLOY RESISTOR
VISHAY-DALE
RWR81S6R98FRB12

FOX-ME-126-07
ANTENNA POST, DELRIN
BONDED INTO THRU HOLE

TOP SIDE



6,00 [0.236]



BOTTOM SIDE



ISO VIEW
ANTENNA AREA
SCALE 2 : 1

AMSAT
FOX

Y SIDE SOLAR PANEL

SIZE	DATE	DWG. NO.	REV.
A	2013-06-11	FOX-ME-127	0.7
SCALE	1 : 1	UNLESS NOTED OTHERWISE:	SHEET 2 OF 4
		mm [in] TOL. X.X ± 0.2 X.XX ± 0.1	

- ASSEMBLY INSTRUCTIONS
-01 +Y (437MHZ RX ANTENNA POINTING +Z) OR -03 -Y (144 TX ANTENNA POINTING IN -Z)
- 1) SOLDER CONNECTOR, MMCX, RESISTOR, RF SMD COMPONENTS, THERMISTOR AND COPPER ANTENNA POST.
 - 2) BOND G10/FR4 ANTENNA POSTS.
 - 3) FILL CONNECTOR ALIGNMENT HOLES AS NECESSARY TO PREVENT VOID UNDER CIC.
 - 4) BOND & SOLDER CICS.
 - 5) SOLDER TORSION SPRING ANTENNA (ENTIRE LENGTH OF BENT LEG AND INTO THRU HOLE BUT NOT COIL) AND STOP WIRE (BEND AS REQUIRED FOR PROPER DEPLOYED ANGLE).

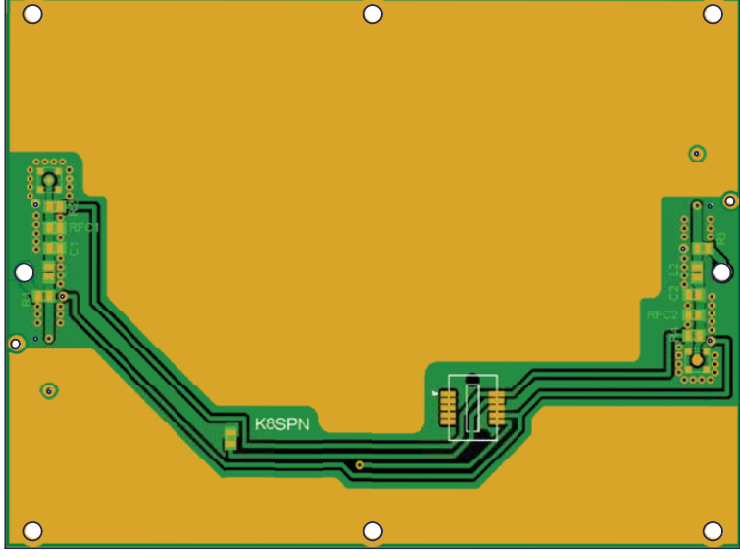
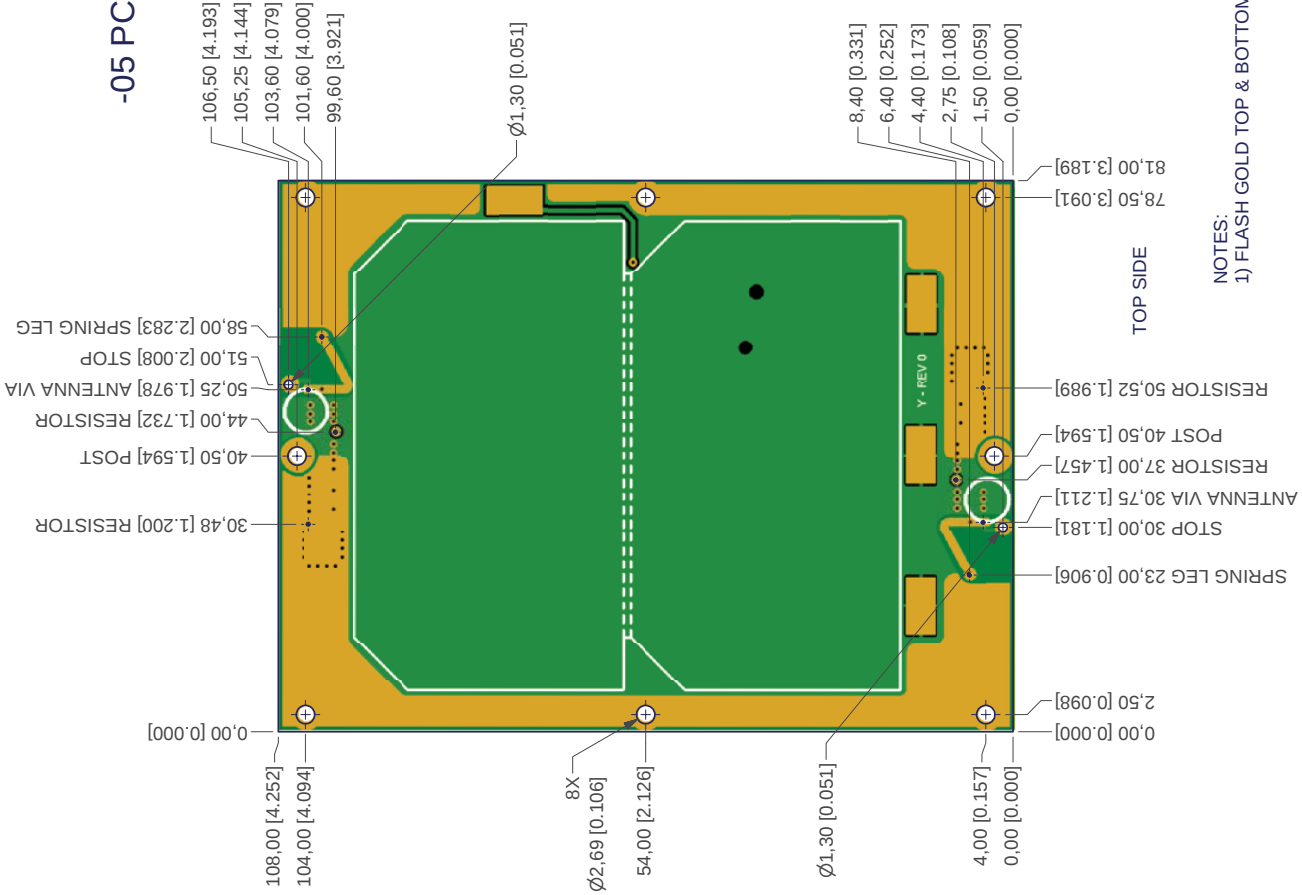
1	1	FOX-ME-127-05	PCB
4	1	SAMTEC MEC1-105-02-S-D-NP-A	EDGE CARD CONNECTOR
5	1		THERMISTOR, 0805
6	1	FOX-ME-126-05	ANTENNA POST, COPPER
7	1	FOX-ME-126-07	ANTENNA POST, G10/FR4
8	1	MOLEX 73415-2061	MMCX JACK, 50 OHM SMD
9	1	VISHAY-DALE RWR81S0R98FRB12	WIREWOUND RESISTOR, 6.98 OHM
10	1	FOX-ME-128	TORSION SPRING ANTENNA
20	2	ANTENNA STOP	Ø1MM BC WIRE
21	2	FOX-ME-122	SpaceQuest UTJ
ITEM	QTY	PART NUMBER	DESCRIPTION
Parts List			

AMSAT
FOX

Y SIDE SOLAR PANEL

SIZE	DATE	DWG. NO.	REV.
A	2013-06-11	FOX-ME-127	0.7
SCALE	1 : 1	UNLESS NOTED OTHERWISE: mm [in] TOL. X.X ± 0.2 X.XX ± 0.1	SHEET 3 OF 4

-05 PCB



TOP SIDE

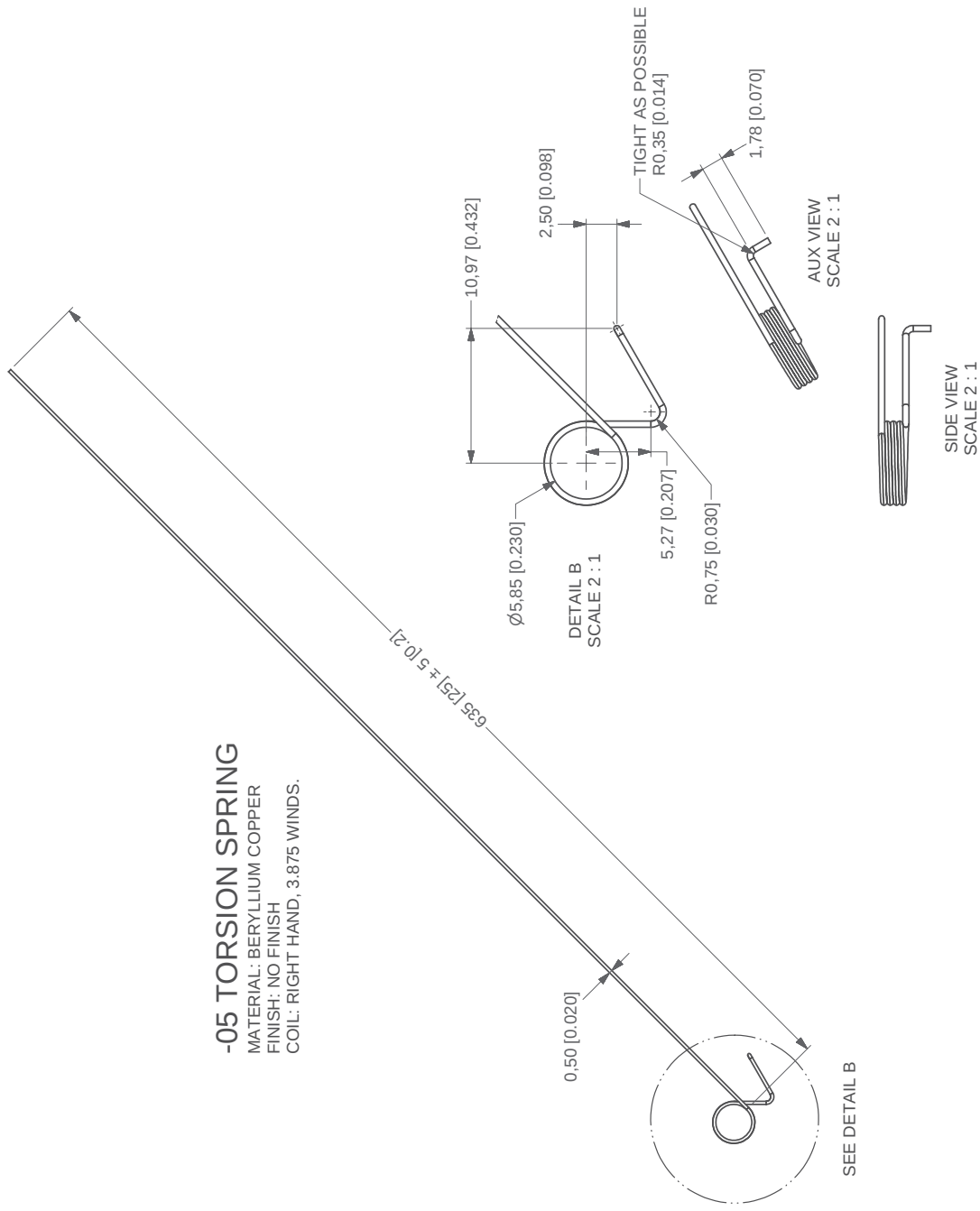
BOTTOM SIDE

AMSAT FOX			
Y SIDE SOLAR PANEL			
SIZE	DATE	DWG.NO	REV.
A	2013-06-11	FOX-ME-127	0.7
SCALE	1 : 1	UNLESS NOTED OTHERWISE:	SHEET
		mm [in] TOL. X.X ± 0.2 X.XX ± 0.1	4 OF 4

NOTES:
1) FLASH GOLD TOP & BOTTOM SIDES, ANY AVAILABLE AREAS.

-05 TORSION SPRING

MATERIAL: BERYLLIUM COPPER
FINISH: NO FINISH
COIL: RIGHT HAND, 3.875 WINDS.



ANTENNA				
SIZE	DATE	DWG. NO.	REV.	
A	2013-05-29	FOX-ME-128	0.2	
SCALE			SHEET	
1 : 1			2 OF 3	
UNLESS NOTED OTHERWISE: mm [in] TOL. XX ± 0.2 XXX ± 0.1				

AMSAT

FOX

SAFE RBF

DATE

2013-06-06

DWG. NO.

FOX-ME-130

REV.

0.1

SIZE

A

SCALE

1 : 1

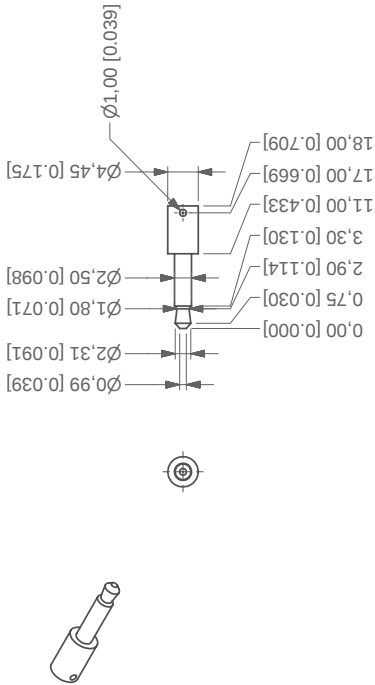
UNLESS NOTED OTHERWISE:

mm [in] TOL. X.X ± 0.2 X.XX ± 0.1

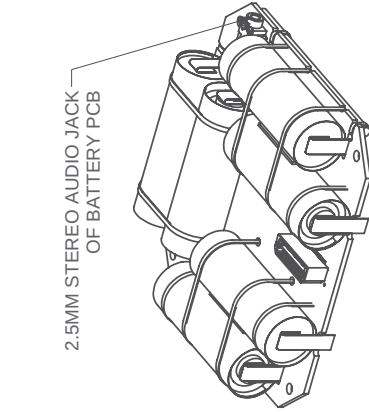
SHEET

1 OF 4

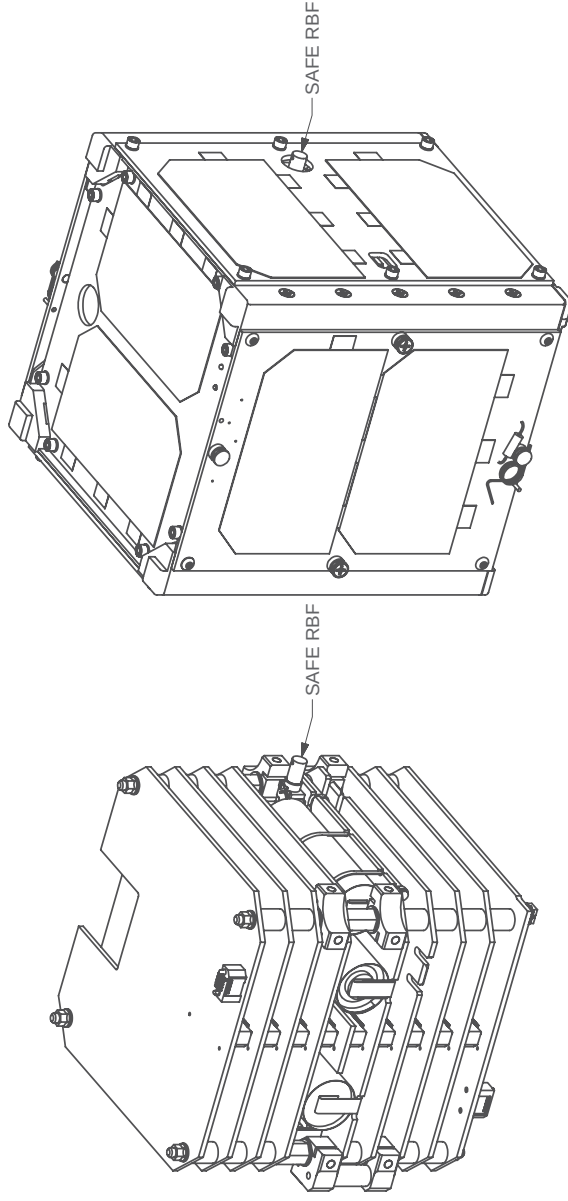
NOTES:
1) MATERIAL: NICKEL ALLOY 200/201
2) A FINGER-SIZED LOOP OF RED WIRE OR LACING CORD (NOT SHOWN) MAY BE USED THRU HOLE.



ON PCB-STACK
(+X EDGE OF BATTERY PCB)



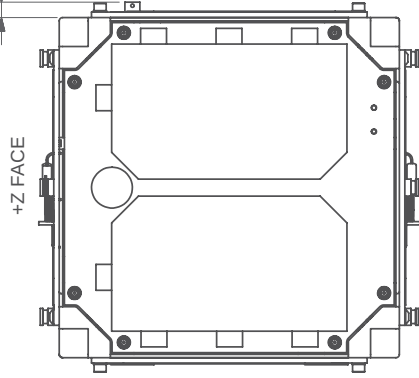
ON FOX-1
(ROUND HOLE IN +X SOLAR PANEL)



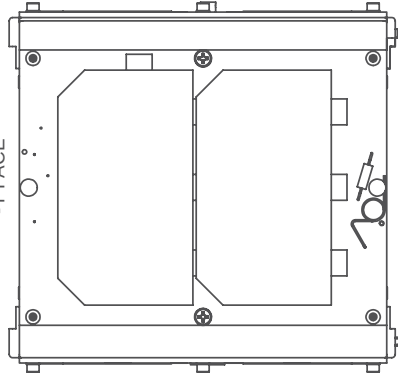
- NOTES:
- 3) TO SAFE (DISABLE) ELECTRONICS:
FULLY INSERT INTO AUDIO JACK ON +X SIDE OF BATTERY BOARD
(ROUND HOLE IN +X SOLAR PANEL).
 - 4) TO ARM (ENABLE) ELECTRONICS:
FULLY REMOVE.

SAFE RBF			
SIZE	DATE	DWG NO.	REV.
A	2013-06-06	FOX-ME-130	0.1
SCALE		SHEET	
1 : 2		2 OF 4	
UNLESS NOTED OTHERWISE: mm [in] TOL. XX ±0.2 X.XX ±0.1			

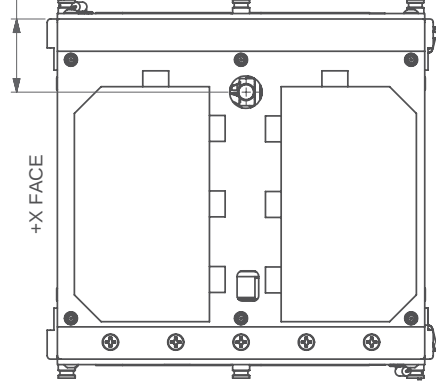
PROTRUDES 4.5 [0.18]
 INTO 6.50 [0.256]
 ALLOWABLE ENVELOPE
 INSIDE P-POD



-Y FACE



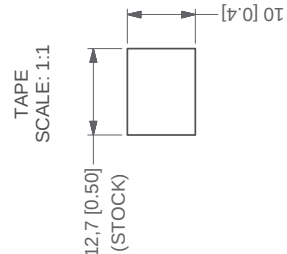
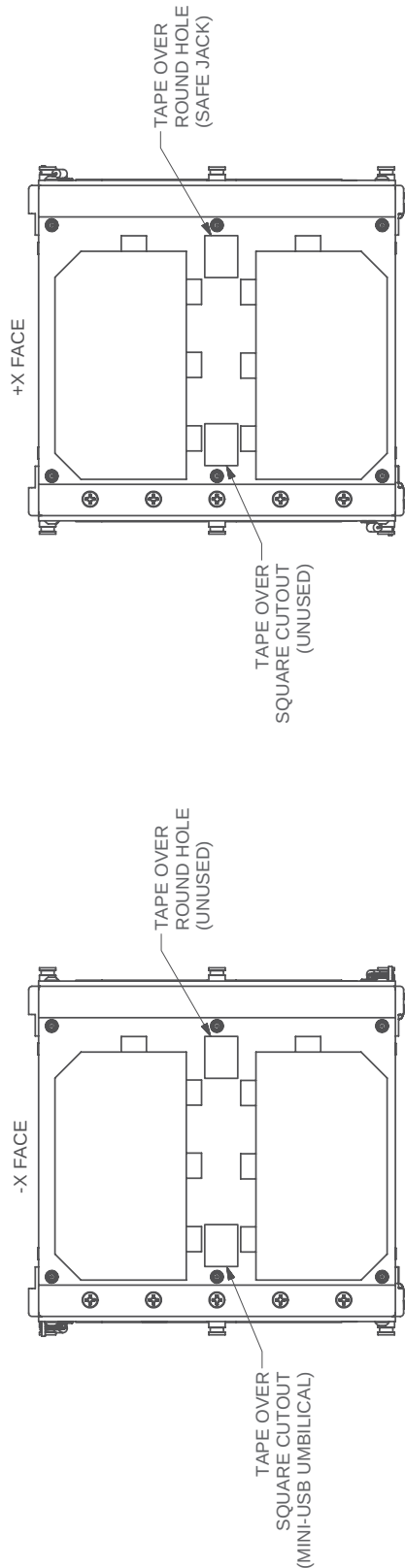
+X FACE



21,5 [0.85]
 FULLY VISIBLE IN
 P-POD ACCESS PORT
 13.75 MM FROM RAIL,
 WHETHER CUBESAT LOADED
 INTO P-POD -Z OR +Z END FIRST

- NOTES:
- 5) COMPATIBLE WITH P-POD ALLOWABLE ENVELOPE.
 - 6) REMOVE BEFORE FLIGHT (RBF) ITEM.

SAFE RBF				
SIZE	DATE	DWG. NO.	REV.	
A	2013-06-06	FOX-ME-130	0.1	
SCALE	1 : 2	UNLESS NOTED OTHERWISE:		
		mm [in]: TOL. XX ±0.2 XXX ±0.1		
			SHEET	3 OF 4



NOTES:
 7) UMBILICAL HOLES TO BE COVERED FOR FLIGHT USING APPROVED 1ST SURF METAL TAPE. FOR SAFE RBF, AND POSSIBLY ALSO THE MINI-USB, THIS MAY HAVE TO BE PERFORMED THROUGH ACCESS PORT(S) INSIDE P-POD.

SAFE RBF				
SIZE	DATE	DWG NO.	REV	
A	2013-06-06	FOX-ME-130	0.1	
SCALE			SHEET	4 OF 4
1 : 2			UNLESS NOTED OTHERWISE: mm [in] TOL. XX ±0.2 XXX ±0.1	